

Physics NCERT Compilation

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1. Electric current

1.1 Electric charges: Like charges and unlike charges

- In 1752 **Benjamin Franklin**, an American scientist, showed that lightning and the spark from clothes are essentially the same phenomena.
- When a plastic refill is rubbed with polythene, it acquires a small electric charge.
- Similarly, when a plastic comb is rubbed with dry hair, it acquires a small charge.
- These objects are called charged objects.
- The electrical charges produced by rubbing are called **static charges**.
- When charges move, they constitute an **electric current**.
- Electrical charge can be transferred from a charged object to another through a metal conductor.
- The process of transferring of charge from a charged object to the earth is called **earthing**.
- Earthing is provided in buildings to protect us from electrical shocks due to any leakage of electrical current.
- In the process of charging the refill and the plastic comb, polythene and hair also get charged (**loss of charge in one object is compensated by the gain of charge in the other**).
- An object that loses charge (electrons), is said to be positively charged because it has an excess of protons.
- An object that gains charge (electrons), is said to be negatively charged.
- **Like charges repel while the unlike charges attract.**

Experiment

- Inflate two balloons. Hang them in such a way that they do not touch each other. Rub both the balloons with a woollen cloth and release them. What do you observe? (They repel each other)



Like charges repel each other

- Rub a refill with a polythene and place it gently in a glass tumbler. Bring an inflated charged balloon near the refill and observe. The charged balloon will attract a charged refill.



Unlike charges attract each other



A simple electroscope

- The aluminium foil strips in the jar receive the same charge from the charged refill.
- The strips carrying similar charges repel each other and they become wide open.

- Such a device can be used to test whether an object is carrying charge or not.
- This device is known as **electroscope**.

Lightning (Explained in Geography > Climatology)

- During the development of a thunderstorm, the air currents move upward while the water droplets move downward. These vigorous movements cause **separation of charges**.
- By a process, not yet completely understood, the **positive charges collect near the upper edges of the clouds and the negative charges accumulate near the lower edges**.
- **There is accumulation of positive charges near the ground also.**
- When the magnitude of the accumulated charges becomes very large, the air which is normally a poor conductor of electricity, is no longer able to resist their flow.
- Negative and positive charges meet, producing streaks of bright light and sound. We see streaks as lightning. The process is called an **electric discharge**.



Accumulation of charges leading to lightning.

Do's and Don'ts during a Thunderstorm

Outside the house

- Open vehicles, like motorbikes, tractors, construction machinery, open cars are not safe.
- Open fields, tall trees, shelters in parks, elevated places do not protect us from lightning strokes.

- Carrying umbrella is not a good idea at all during thunderstorms.
- If in a forest, take shelter under shorter trees.
- If no shelter is available and you are in an open field, stay far away from all trees.
- Stay away from poles or other metal objects.
- Do not lie on the ground. Instead, squat low on the ground. This position will make you the smallest target.



Inside the house

- Lightning can strike telephone cords, electrical wires and metal pipes. During a thunderstorm contact with these should be avoided.
- It is safer to use mobile phones and cordless phones. However, it is not wise to call up a person who is receiving your phone through a wired phone.
- Bathing should be avoided during thunderstorms to avoid contact with running water.
- Electrical appliances like computers, TVs, etc., should be unplugged.

Lightning Conductors

- Lightning Conductor is a device **used to protect buildings from the effect of lightning.**
- A metallic rod, taller than the building, is installed in the walls of the building during its construction.
- One end of the rod is kept out in the air and the other is buried deep in the ground.
- The rod provides easy route for the transfer of electric charge to the ground.
- The metal columns used during construction, electrical wires and water pipes in the buildings also protect us to an extent. But do not touch them during a thunderstorm.



1.2 Electric current

- Electric current is expressed by the **amount of charge flowing through a particular area in unit time**.
- In other words, it is the **rate of flow of electric charges**.
- A continuous and closed path of an electric current is called an electric circuit.
- Conventionally, in an electric circuit the direction of **electric current is taken as opposite to the direction of the flow of electrons**.
- If a net charge Q , flows across any cross-section of a conductor in time t , then the current I , through the cross-section is **$I = Q/t$** .
- The SI unit of electric charge is **coulomb (C)**, which is equivalent to the charge contained in nearly **6×10^{18} electrons**. (electron possesses a negative charge of $1.6 \times 10^{-19} \text{ C}$)
- The electric current is expressed by a unit called **ampere (A)**, named after the French scientist, Andre-Marie Ampere (1775-1836).
- **One ampere is constituted by the flow of one coulomb of charge per second**.
- Small quantities of current are expressed in milliampere ($1 \text{ mA} = 10^{-3} \text{ A}$) or in microampere (10^{-6} A).
- An instrument called **ammeter** measures electric current in a circuit.
- It is always **connected in series** in a circuit through which the current is to be measured.

*The credit for the invention of the **electric bulb** is usually given to **Thomas Alva Edison**, though others before him had worked on it.*

Edison made some 1300 inventions including the electric bulb, gramophone, the motion picture camera and the carbon transmitter, which facilitated the invention of the telephone.

1.3 'Flow' of charges inside a wire

- A low-energy electron would have great difficulty passing through a solid conductor as the atoms are packed together with very little spacing between them.
- But it turns out that the electrons are able to 'travel' through a perfect solid crystal smoothly and easily.
- The 'motion' of electrons in a conductor, however, is very different from that of charges in empty space.
- When steady current flows through a conductor, the electrons in it move with a certain average '**drift speed**'.
- For a typical copper wire carrying a small current, drift speed it is found to be **of the order of 1 mm per second (electrons move at snail's pace in a conductor)**.

How is it then that an electric bulb lights up as soon as we turn the switch on?

- Think of a tube filled with marbles: if you add a marble at one end, a marble will come out the other end at almost the same instant, even though each marble didn't move that far on its own.
- Likewise, a copper wire contains lots of electrons. The electrons are packed in so tightly that even a small movement will travel down the wire from electron to electron at an impressive speed, letting you turn on the lights without having to wait for electrons to travel the whole way there.

1.4 Electric potential and potential difference

- Charges do not flow in a copper wire by themselves, just as water in a perfectly horizontal tube does not flow.
- For flow of charges in a conducting metallic wire, the electrons move only if there is a difference of electric pressure - called the **potential difference** - along the conductor.
- This difference of potential may be produced by a battery, consisting of one or more electric cells.
- The **chemical action within a cell** generates the potential difference across the terminals of the cell.
- When the cell is connected to a conducting circuit element, the potential difference sets the charges in motion in the conductor and produces an electric current.
- In order to maintain the current in a given electric circuit, the cell has to expend its chemical energy.
- We define the electric potential difference between two points in an electric circuit carrying some current as the **work done to move a unit charge from one point to the other**.
- Potential difference (V) between two points = **Work done (W)/Charge (Q) = $V = W/Q$**
- The SI unit of electric potential difference is **volt (V)**, named after Alessandro Volta (1745-1827), an Italian physicist.
- One volt is the potential difference between two points in a current carrying conductor when 1 joule of work is done to move a charge of 1 coulomb from one point to the other.

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

$$1 \text{ V} = 1 \text{ J C}^{-1}$$

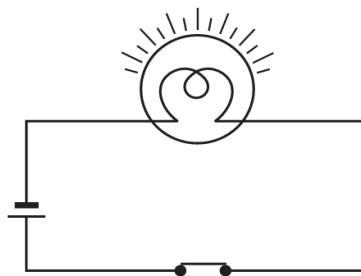
- The potential difference is measured by means of an instrument called the **voltmeter**.
- The voltmeter is always **connected in parallel** (**ammeter is connected in series**) across the points between which the potential difference is to be measured.

Questions

- Name a device that helps to maintain a potential difference across a conductor. (Ans: Battery)
- What is meant by saying that the potential difference between two points is 1 V? (Ans: One Joule of work done by One Coulomb of charge)

1.5 Components of an electric circuit and their symbols

- It is convenient to represent electric components by symbols.
- Using these, an electric circuit can be represented by a circuit diagram.



A simple Circuit Diagram

Sl. No.	Components	Symbols
1	An electric cell	
2	A battery or a combination of cells	
3	Plug key or switch (open)	
4	Plug key or switch (closed)	
5	A wire joint	
6	Wires crossing without joining	
7	Electric bulb	
8	A resistor of resistance R	
9	Variable resistance or rheostat	
10	Ammeter	
11	Voltmeter	

1.6 Ohms law

- In 1827, a German physicist Georg Simon Ohm (1787-1854) found out the relationship between the current I , flowing in a metallic wire and the potential difference across its terminals.
- He stated that the **electric current flowing through a metallic wire is directly proportional to the potential difference V** , across its ends provided its temperature remains the same. This is called Ohm's law.

$$\begin{aligned}
 & V \propto I \\
 \text{or} \quad & V/I = \text{constant} \\
 & = R \\
 \text{or} \quad & V = IR
 \end{aligned}$$

- R is a constant for the given metallic wire at a given temperature and is called its **resistance**.
- It is the property of a conductor to resist the flow of charges through it.
- Its SI unit is ohm, represented by the Greek letter Ω .
- According to Ohm's law, $R = V/I$.

- If the potential difference across the two ends of a conductor is 1 V and the current through it is 1 A, then the resistance R , of the conductor is 1 Ω .
- **Ohm's law holds true for semiconductors**, but **for a wide variety of materials (such as metals) the resistance is fixed and does not depend on the amount of current or the amount of voltage**.

Resistance

- The electrons, not completely free to move within a conductor. They are restrained by the attraction of the atoms among which they move. Thus, motion of electrons through a conductor is retarded by its resistance.
- A component of a given size that offers a low resistance is a good conductor.
- A conductor having some appreciable resistance is called a resistor.
- A component of identical size that offers a higher resistance is a poor conductor.
- An insulator of the same size offers even higher resistance.
- Resistance of the conductor depends
 - a) **on its length (greater the length, greater is the resistance, and greater is the transmission loss),**
 - b) **on its area of cross-section (greater the cross-section, lesser is the resistance), and**
 - c) **on the nature of its material.**
- Precise measurements have shown that resistance of a uniform metallic conductor is directly proportional to its length (l) and inversely proportional to the area of cross-section (A).
- That is,

$$R \propto \frac{l}{A}$$

$$R = \rho \frac{l}{A}$$

- where ρ (rho) is a constant of proportionality and is called the **electrical resistivity** of the material.
- The SI unit of resistivity is **$\Omega \text{ m}$** . It is a characteristic property of the material.
- The metals and alloys have very low resistivity. They are good conductors of electricity.
- The resistivity of an alloy is generally higher than that of its constituent metals.
- **Alloys do not oxidise (burn) readily at high temperatures**. For this reason, they are commonly used in electrical heating devices, like electric iron, toasters etc.
- **Tungsten** is used almost exclusively for filaments of electric bulbs, whereas copper and aluminium are generally used for electrical transmission lines.
- Insulators like rubber and glass have resistivity.

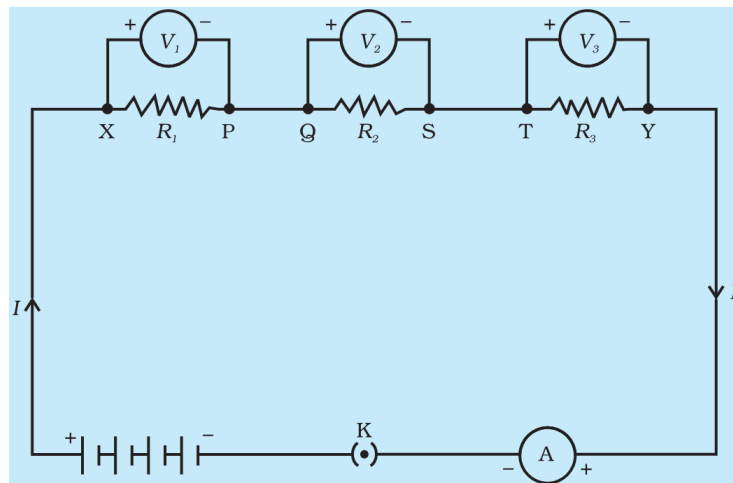
- Both the resistance and resistivity of a material vary with temperature.

	Material	Resistivity ($\Omega \text{ m}$)
Conductors	Silver	1.60×10^{-8}
	Copper	1.62×10^{-8}
	Aluminium	2.63×10^{-8}
	Tungsten	5.20×10^{-8}
	Nickel	6.84×10^{-8}
	Iron	10.0×10^{-8}
	Chromium	12.9×10^{-8}
	Mercury	94.0×10^{-8}
	Manganese	1.84×10^{-6}
Alloys	Constantan (alloy of Cu and Ni)	49×10^{-6}
	Manganin (alloy of Cu, Mn and Ni)	44×10^{-6}
	Nichrome (alloy of Ni, Cr, Mn and Fe)	100×10^{-6}
Insulators	Glass	$10^{10} - 10^{14}$
	Hard rubber	$10^{13} - 10^{16}$
	Ebonite	$10^{15} - 10^{17}$
	Diamond	$10^{12} - 10^{13}$
	Paper (dry)	10^{12}

Resistor

- A resistor is an electrical component that implements electrical resistance as a circuit element.
- In electronic circuits, resistors are used to reduce current flow, adjust signal levels, etc.
- Current through a resistor is inversely proportional to its resistance.** If the resistance is doubled the current gets halved.
- A component used to regulate current without changing the voltage source is called **variable resistance**.
- In an electric circuit, a device called **rheostat** is often used to change the resistance in the circuit.

Resistors in Series



- The potential difference V is equal to the sum of potential differences V_1 , V_2 , and V_3 .
- That is the total potential difference across a combination of resistors in series is equal to the sum of potential difference across the individual resistors.
- That is,

$$V = V_1 + V_2 + V_3 = IR = IR_1 + IR_2 + IR_3 = I(R_1 + R_2 + R_3)$$

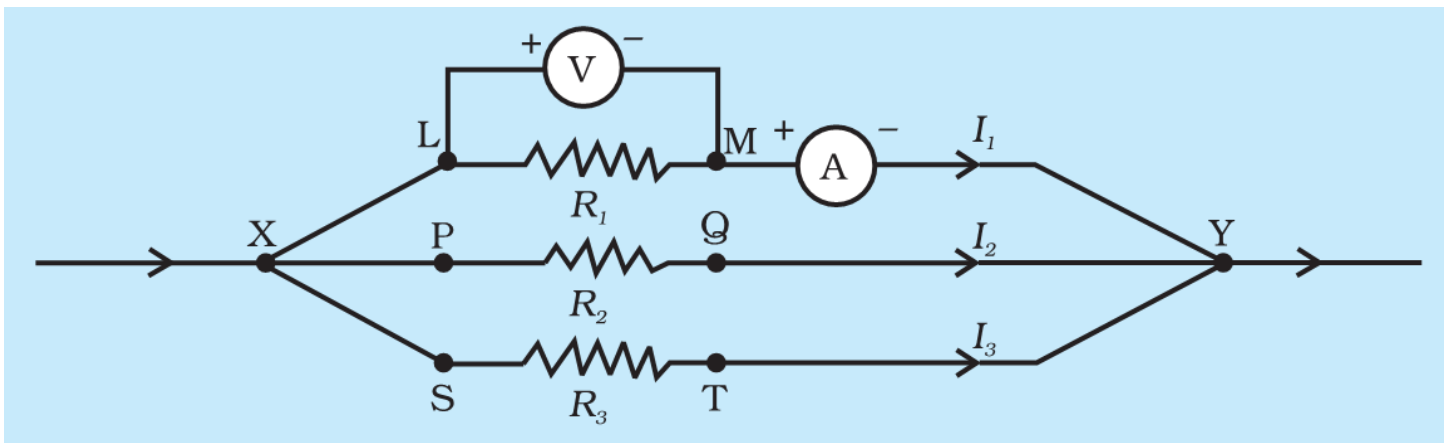
That is, **$R_s = R_1 + R_2 + R_3$**

- We can conclude that when several resistors are joined in series, the resistance of the combination R_s equals the sum of their individual resistances, R_1 , R_2 , R_3 , and is thus greater than any individual resistance.

Disadvantages of series circuit

- In a series circuit the current is constant throughout the electric circuit. Thus, it is obviously impracticable to connect an electric bulb and an electric heater in series, because they need currents of widely different values to operate properly.
- Another major disadvantage of a series circuit is that when one component fails the circuit is broken and none of the components works.

Resistors in Parallel



- It is observed that the total current I , is equal to the sum of the separate currents through each branch of the combination.

$$I = I_1 + I_2 + I_3 = V/R = V/R_1 + V/R_2 + V/R_3 \text{ or } \mathbf{1/R_p = 1/R_1 + 1/R_2 + 1/R_3}$$

- Thus, we may conclude that the reciprocal of the equivalent resistance of a group of resistances joined in parallel is equal to the sum of the reciprocals of the individual resistances.
- That is, **the total resistance in a parallel circuit is decreased**.
- Parallel circuits are helpful when each gadget has different resistance and requires different current to operate properly.

1.7 Electric power

- Electric power is the rate of consumption of energy = Voltage x Electric Current.

$$\mathbf{P = VI = (IR) I = I^2R = V^2 / R}$$

- The SI unit of electric power is **watt (W)**. It is the power consumed by a device that carries 1 A of current when operated at a potential difference of 1 V. Thus, 1 W = 1 volt x 1 ampere = 1 V A.
- The unit 'watt' is very small. Therefore, we use a much larger unit called **kilowatt (1000 watts)**.
- Since energy is the product of **power and time**, the unit of electric energy is, therefore, **watt hour (Wh)**.
- One watt hour is the energy consumed when 1 watt of power is used for 1 hour.
- The commercial unit of electric energy is **kilowatt hour (kWh)**, commonly known as **unit**.
- 1 kW h = 1000 watt x 3600 second = 3.6 x 10⁶ watt second = 3.6 x 10⁶ joule (J)**

Questions

- Why is the tungsten used almost exclusively for filament of electric lamps?

- Why are the conductors of electric heating devices, such as bread-toasters and electric irons, made of an alloy rather than a pure metal?
- Why is the series arrangement not used for domestic circuits?
- Why are copper and aluminium wires usually employed for electricity transmission?

1.8 Chemical Effects of Electric Current

- The passage of an electric current through a conducting liquid causes chemical reactions.
- The resulting effects are called chemical effects of currents.
- British chemist, William Nicholson (1753-1815), had shown that if electrodes were immersed in water, and a current was passed, bubbles of oxygen and hydrogen were produced.
- Oxygen bubbles formed on the electrode connected to the positive terminal of the battery and hydrogen bubbles formed on the other electrode.
- The passage of an electric current through a conducting solution causes chemical reactions.
- As a result, bubbles of a gas may be formed on the electrodes.
- Deposits of metal may be seen on electrodes.
- Changes of colour of solutions may occur.
- The reaction would depend on what solution and electrodes are used.

Electric Cell

- All electric cells have two terminals; a **positive terminal (anode)** and a **negative terminal (cathode)**.
- An electric cell produces electricity from the chemicals stored inside it (chemical energy to electrical energy).
- The electric circuit provides a complete path for electricity to pass between the two terminals.
- In an electric circuit, the direction of current is taken to be from the **positive to the negative terminal**.



Direction of current in a closed circuit

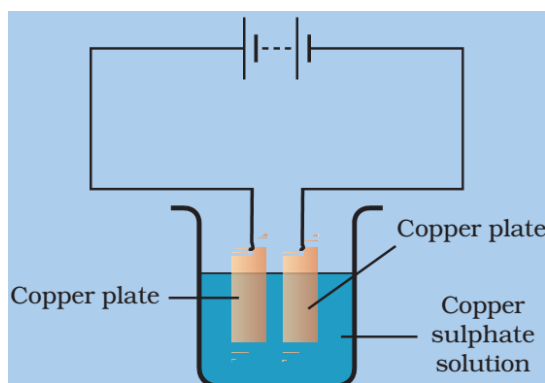
- A switch is a simple device that either breaks the circuit or completes it.
- Materials which allow electric current to pass through them are conductors of electricity.
- Insulators do not allow electric current to pass through them.

Electric Conductivity in liquids

- Most liquids that conduct electricity are solutions of **acids, bases** and **salts**.
- Distilled water (pure water free of salts) doesn't conduct electricity as there are no ions in it.
- Tap water may contain several salts dissolved in it and hence it is a good conductor of electricity.
- Some liquids such as **oil or alcohol do not form ions** and do not conduct electricity.
- Vinegar is mostly water with a small amount of acetic acid in it. The acetic acid separates into ions. Hence **vinegar (weak acid) conducts electricity**.
- Soda compounds (containing sodium) contain ions when dissolved in water and ions help conduct electricity.
- Milk is a good conductor of electricity because it contains water and lactic acids and other salts.
- Lubricants are normally only slightly conductive and therefore can work as insulators in transformers or switches.
- **Sugar solution does not conduct electricity**, because there are no ions in the solution.

Electroplating

- When electric current is passed through the copper sulphate solution, copper sulphate dissociates into copper and sulphate.



- The free copper gets drawn to the electrode connected to the negative terminal of the battery and gets deposited on it. But what about the loss of copper from the solution?
- From the other electrode, a copper plate, an equal amount of copper gets dissolved in the solution. Thus, the loss of copper from the solution is restored and the process keeps going. This means that copper gets transferred from one electrode to the other.

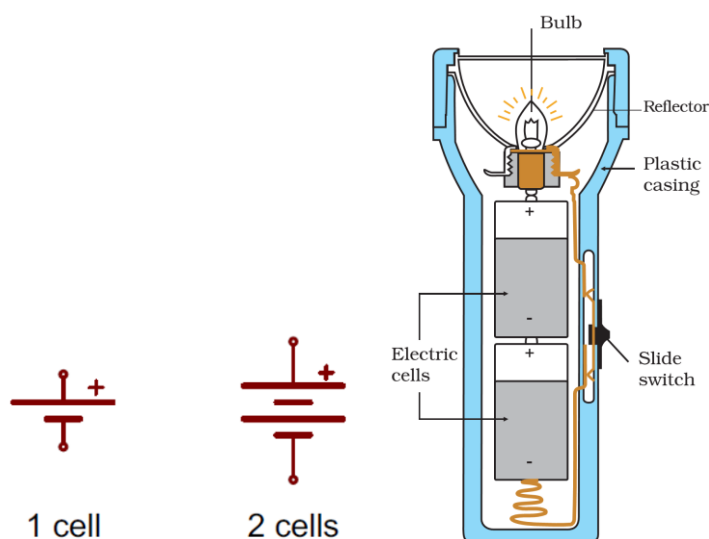
- The process of depositing a layer of any desired metal on another material by means of electricity is called electroplating. It is one of the most common applications of chemical effects of electric current.

Examples of electroplating

- Chromium plating is done on many objects such as bath taps, wheel rims and many others.
- **Chromium has a shiny appearance. It does not corrode. It resists scratches.**
- However, chromium is expensive, and it may not be economical to make the whole object out of chromium.
- So, the object is made from a cheaper metal and only a coating of chromium over it is deposited.
- Jewellery makers electroplate silver and gold on less expensive metals.
- **Tin cans, used for storing food**, are made by electroplating tin onto iron. Tin is less reactive than iron. Thus, food does not come into contact with iron and is protected from getting spoilt.
- Iron is used in bridges and automobiles to provide strength. However, iron tends to corrode and rust. So, a **coating of zinc** is deposited on iron to **protect it from corrosion and formation of rust**.
- In the electroplating factories the disposal of the used conducting solution is a major concern. It is a polluting waste and there are specific disposal guidelines to protect the environment.

Questions

- 1) To make a battery of two cells, the negative terminal of one cell is connected to the negative terminal of the other cell. (T/F) (Hint: arrangement of batteries in a torch light)

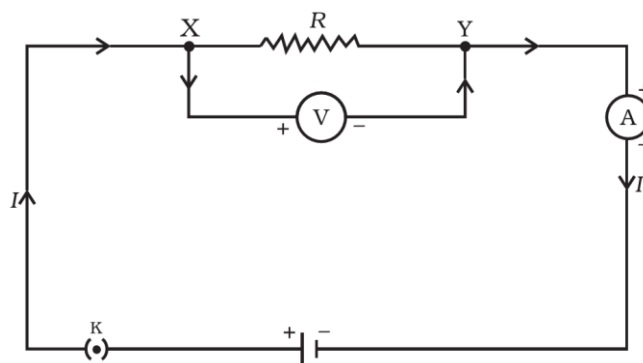


1.9 Heating effect of the electric current

- A part of the source energy in maintaining the current may be consumed into useful work.
- Rest of the source energy may be expended in heat to raise the temperature of gadget.

- For example, an electric fan becomes warm if used continuously for longer time etc.
- On the other hand, if the electric circuit is purely resistive, the source energy continually gets dissipated entirely in the form of heat. This is known as the heating effect of electric current.
- This effect is utilised in devices such as electric heater, electric iron etc.

Joule's law of heating



- Consider a current I flowing through a resistor of resistance R .
- Let the potential difference across it be V . Let t be the time during which a charge Q flows across. The work done in moving the charge Q through a potential difference V is VQ . Therefore, the source must supply energy equal to VQ in time t . Hence the power input to the circuit by the source is

$$P = V \frac{Q}{t} = VI$$

- Or the energy supplied to the circuit by the source in time t is $P \times t$, that is, VIt .
- What happens to this energy expended by the source?
- This energy gets dissipated in the resistor as heat.
- Thus, for a steady current I , the amount of heat H produced in time t is

$$H = VIt$$

- This is known as **Joule's law of heating**.
- The law implies that heat produced in a resistor is
 - a) **directly proportional to the square of current for a given resistance,**
 - b) **directly proportional to resistance for a given current, and**
 - c) **directly proportional to the time for which the current flows through the resistor.**

Practical Applications of Heating Effect of Electric Current

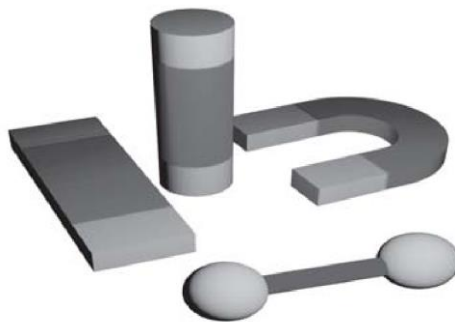
- The electric laundry iron, electric toaster, electric oven, electric kettle and electric heater are some of the familiar devices based on Joule's heating.
- The electric heating is also used to produce light, as in an electric bulb. Here, the filament must retain as much of the heat generated as is possible, so that it gets very hot and emits light.
- It must not melt at such high temperature. A strong metal with high melting point such as **tungsten (melting point 3380°C)** is used for making bulb filaments.
- The filament should be thermally isolated as much as possible, using insulating support, etc.
- The bulbs are usually filled with chemically **inactive nitrogen and argon** gases to prolong the life of filament.
- Another common application of Joule's heating is the fuse used in electric circuits. It protects circuits and appliances by stopping the flow of any unduly high electric current.

Electric fuse

- A wire gets hot when electric current passes through it. This is the heating effect of the electric current.
- The amount of heat produced in a wire depends on its material, length and thickness.
- Wires made from some special materials **melt quickly and break when large electric currents are passed** through them. These wires are used for making electric fuses.
- One reason for excessive currents in electrical circuits is the direct touching of wires.
- This may happen if the insulation on the wires has come off (causing **short circuit**).
- Another reason for excessive current can be the connection of many devices to a single socket (**overload**).
- These days **Miniature circuit breakers (MCBs)** are increasingly being used in place of fuses.
- MCBs are switches which **automatically turn off** when current in a circuit exceeds the safe limit.
- The fuse is placed in series with the device.
- The fuses used for domestic purposes are rated as 1 A, 2 A, 3 A, 5 A, 10 A, etc.
- For an electric iron which consumes 1 kW electric power when operated at 220 V, a current of $(1000/220)$ A, that is, 4.54 A will flow in the circuit. In this case, a 5 A fuse must be used.

2. Magnets

- The substances having the property of attracting iron are now known as magnets.
- Artificial magnets are magnets made from pieces of iron.
- Magnet shapes: bar magnet, horse-shoe magnet, cylindrical or a ballended magnet.

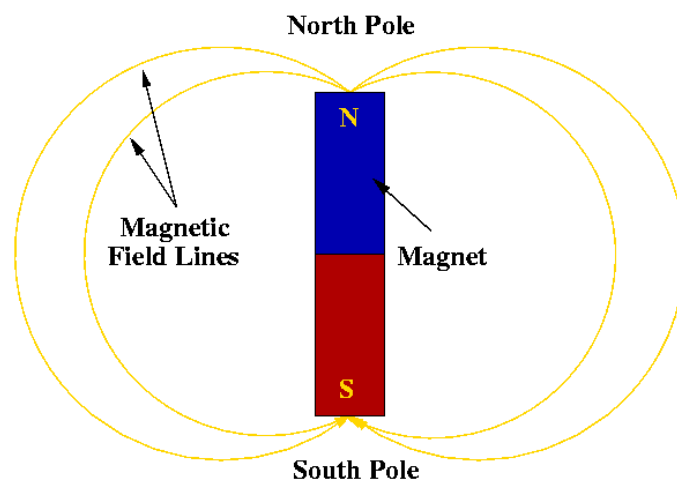
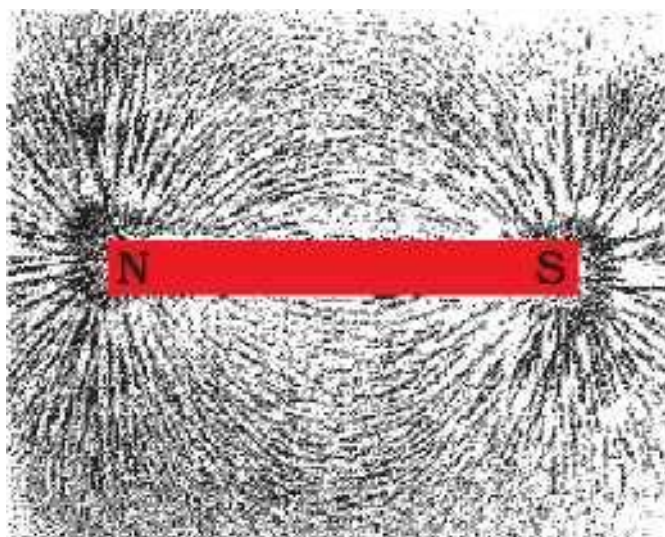


- The materials which get attracted towards a magnet are magnetic – for example, iron, nickel or cobalt.
- Magnets lose their properties if they are heated, hammered or dropped from some height.
- Also, magnets become weak if they are not stored properly.
- To keep them safe, bar magnets should be kept in pairs with their unlike poles on the same side.
- They must be separated by a piece of wood while two pieces of soft iron should be placed across their ends.
- For horse-shoe magnet, one should keep a piece of iron across the poles.

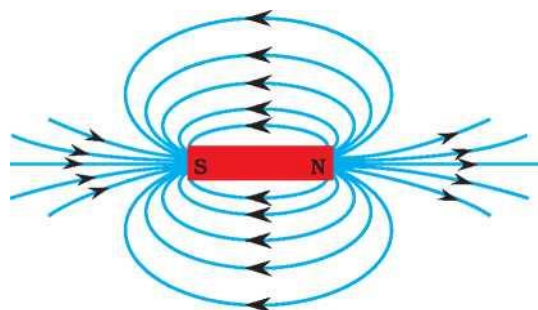


2.1 Magnetic field and field lines

- A compass needle gets deflected when brought near a bar magnet.
- A compass needle is, in fact, a small bar magnet.
- The ends of the compass needle point approximately towards north and south directions.
- The end of the magnet that points towards North is called its North seeking end (North pole) of the magnet.
- The other end that points towards the South is called South seeking end (South pole) of the magnet.
- All magnets have two poles whatever their shape may be.
- Like poles repel, while unlike poles of magnets attract each other.



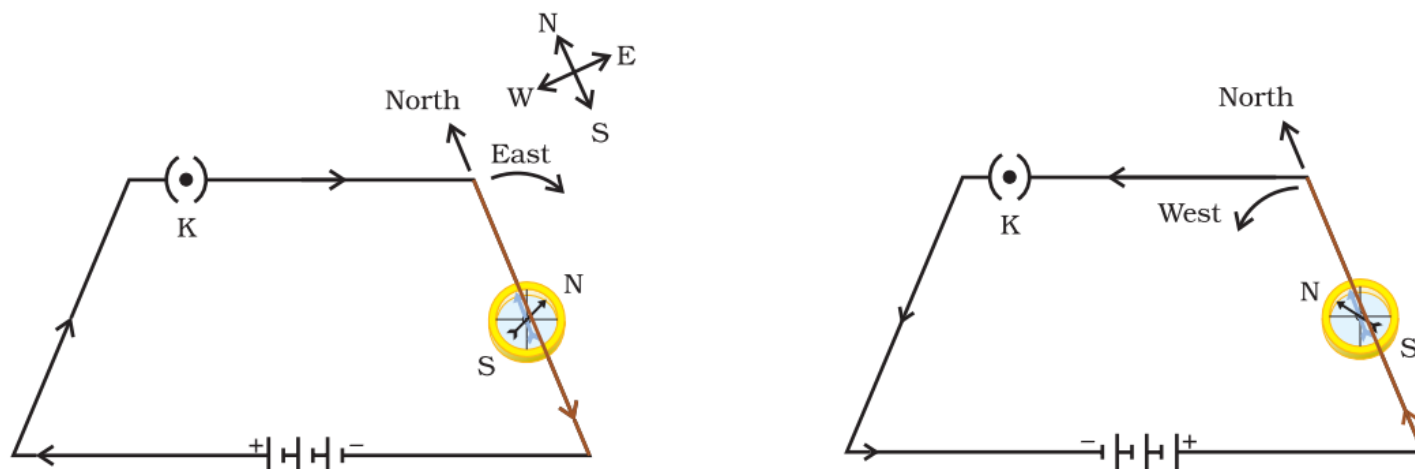
- The magnet exerts its influence in the region surrounding it.
- Therefore, the iron filings around a magnet experience a force.
- The force thus exerted makes iron filings to arrange in a pattern along the field lines.
- The region surrounding a magnet, in which the force of the magnet can be detected, is said to have a magnetic field. The lines along which the iron filings align themselves represent magnetic field lines.



- Magnetic field is a quantity that has both direction and magnitude.
- The direction of the magnetic field is taken to be the direction in which a north pole of the compass needle moves.
- Therefore, it is taken by convention that the field lines **emerge from north pole and merge at the south pole**.
- Inside the magnet, the direction of field lines is from its south pole to its north pole. Thus, the magnetic field lines are closed curves.
- The relative strength of the magnetic field is shown by the degree of closeness of the field lines.
- The field is stronger, that is, the force acting on the pole of another magnet placed is greater where the field lines are crowded.

2.2 Magnetic effect of electric current

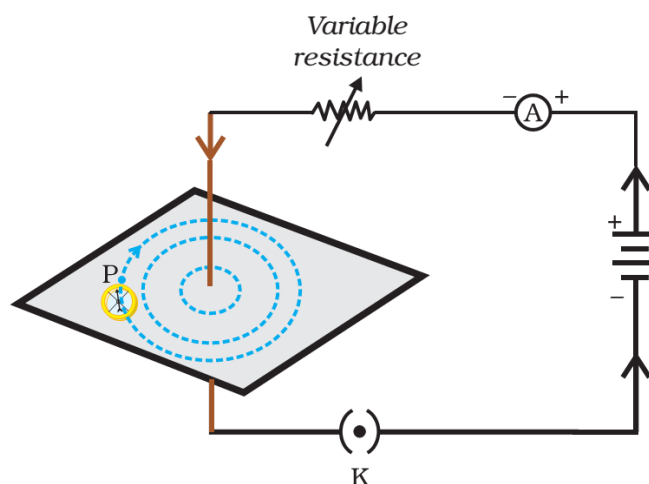
- An electric current through a metallic conductor produces a magnetic field around it.
- If the current flows from north to south, the north pole of the compass needle would move towards the east.
- Replacing the cell connections in the circuit would result in the change of the direction of current through the copper wire, that is, from south to north.
- You will see that now the needle moves in opposite direction, that is, towards the west. It means that the direction of magnetic field produced by the electric current is also reversed.



A simple electric circuit in which a straight copper wire is placed parallel to and over a compass needle. The deflection in the needle becomes opposite when the direction of the current is reversed.

Magnetic Field due to a Current through a Straight Conductor

- The direction of the north pole of the compass needle would give the direction of the field lines produced by the electric current through the straight wire at point P.

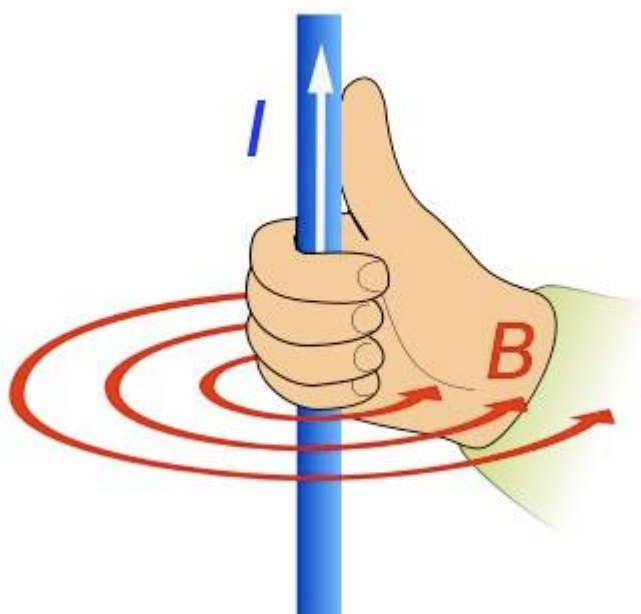


- A pattern of concentric circles indicating the field lines of a magnetic field around a straight conducting wire.

- The arrows in the circles show the direction of the field lines.
- The magnitude of the magnetic field produced at a given **point increases as the current through the wire increases.**
- The magnetic field produced by a given current in the conductor **decreases as the distance from it increases.**

Right-Hand Thumb Rule

- A convenient way of finding the direction of magnetic field associated with a current-carrying conductor is Right-hand thumb rule.

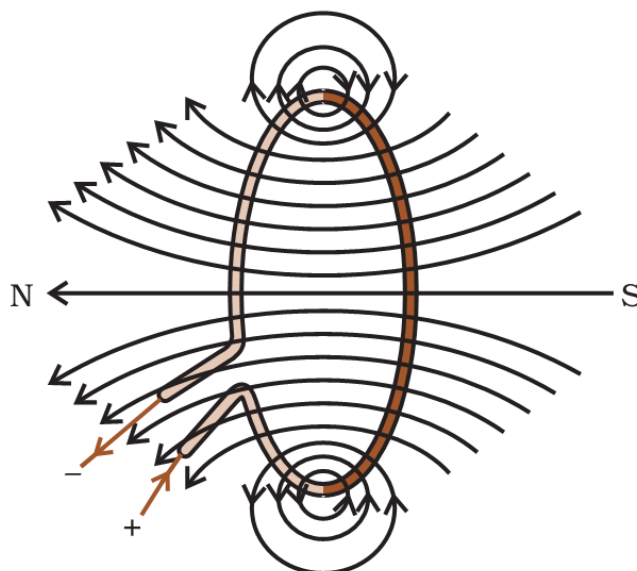


- Imagine that you are holding a current-carrying straight conductor in your right hand such that the thumb points towards the direction of current.
- Then your fingers will wrap around the conductor in the direction of the field lines of the magnetic field. This is known as the right-hand thumb rule.

A current through a horizontal power line flows in east to west direction. What is the direction of magnetic field at a point directly below it and at a point directly above it?

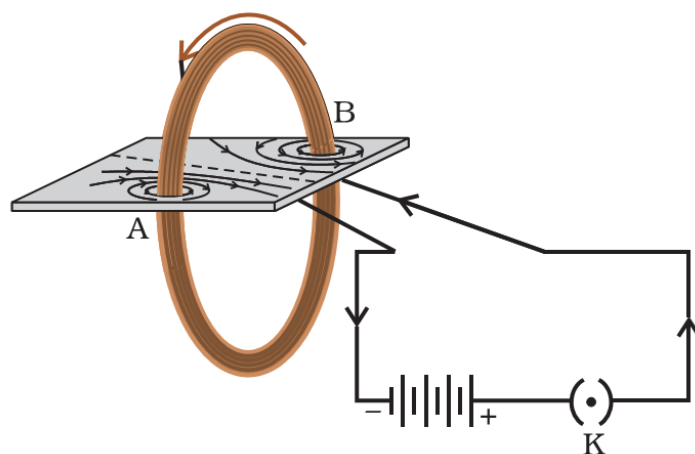
- The current is in the east-west direction. Applying the right-hand thumb rule, we get that the direction of magnetic field at a point below the wire is from north to south.
- The direction of magnetic field at a point directly above the wire is from south to north.

Magnetic Field due to a Current through a Circular Loop



Magnetic field lines of the field produced by a current-carrying circular loop

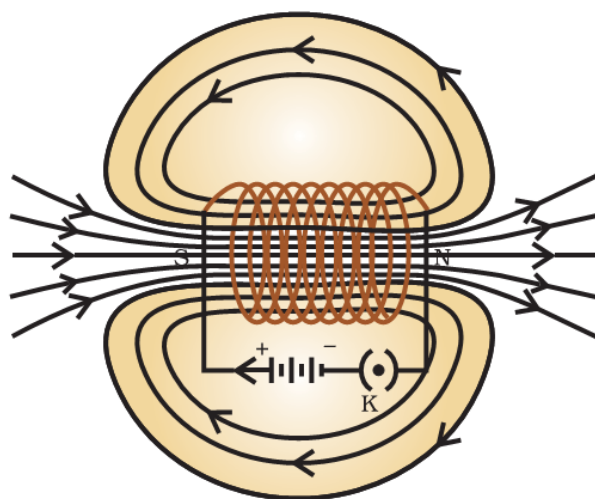
- The magnetic field produced by a current-carrying straight wire depends inversely on the distance from it.
- Similarly, at every point of a current-carrying circular loop, the concentric circles representing the magnetic field around it would become larger and larger as we move away from the wire.
- At the centre of the circular loop, the arcs of these big circles would appear as straight lines.
- Every point on the wire carrying current would give rise to the magnetic field appearing as straight lines at the centre of the loop.
- By applying the right hand rule, it is easy to check that every section of the wire contributes to the magnetic field lines in the same direction within the loop.
- This rule is also called **Maxwell's corkscrew rule**. If we consider ourselves driving a corkscrew in the direction of the current, then the direction of the corkscrew is the direction of the magnetic field.
- We know that the magnetic field produced by a current-carrying wire at a given point depends directly on the current passing through it.
- Therefore, if there is a circular coil having n turns, the field produced is n times as large as that produced by a single turn.
- This is because the current in each circular turn has the same direction, and the field due to each turn then just adds up.



Magnetic field produced by a current carrying circular coil

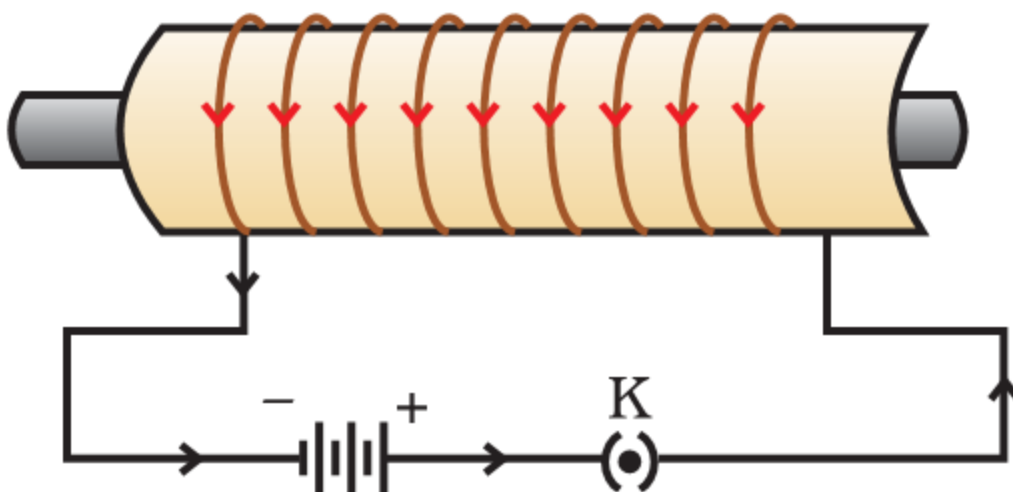
Magnetic Field due to a Current in a Solenoid

- A coil of many circular turns of insulated copper wire wrapped closely in the shape of a cylinder is called a **solenoid**.



The pattern of the magnetic field lines around a current-carrying solenoid

- One end of the solenoid behaves as a magnetic north pole, while the other behaves as the south pole.
- The field lines inside the solenoid are in the form of parallel straight lines. This indicates that the magnetic field **is the same at all points inside the solenoid**. That is, the **field is uniform inside the solenoid**.
- A strong magnetic field produced inside a solenoid can be used to magnetise a piece of magnetic material, like soft iron, when placed inside the coil. The magnet so formed is called an **electromagnet**.

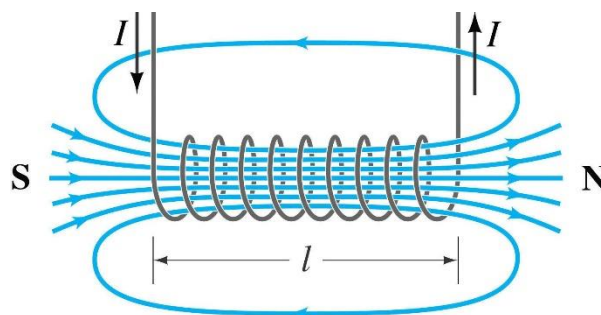


A current-carrying solenoid coil is used to magnetise steel rod inside it - an electromagnet.

Question: The magnetic field inside a long straight solenoid-carrying current

- a) is zero.
- b) decreases as we move towards its end.
- c) increases as we move towards its end.
- d) is the same at all points.

Explanation: In case of a current carrying coil, the magnetic field of each loop adds up to produce a net magnetic field. But in case of solenoid each loop is separated by a distance and the magnetic field at the centre of each loop is same.



Solenoid acts as a simple bar magnet

Ans: d) is the same at all points.

Application of Electromagnets

- When the electric current is switched off, the wire or coil generally loses its magnetism. Such wires or coils are called **electromagnets**.
- The electromagnets are used on the track for a **maglev train**.

- The electromagnets can be made very strong and can **lift very heavy loads**.
- Electromagnets are used in **electric bell**.



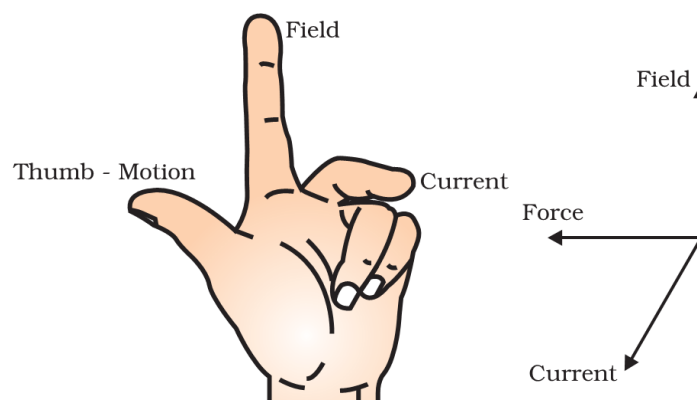
The coil in the bell acts as an electromagnet when electricity is passed through it.

Hans Christian Oersted (1777-1851)

- Hans Christian Oersted, one of the leading scientists of the 19th century, played a crucial role in understanding **electromagnetism**.
- In 1820 he accidentally discovered that a compass needle got deflected when an electric current passed through a metallic wire placed nearby.
- Through this observation Oersted showed that electricity and magnetism were related phenomena.
- His research later created technologies such as the radio, television and fiber optics.
- The unit of magnetic field strength is named the Oersted in his honour.

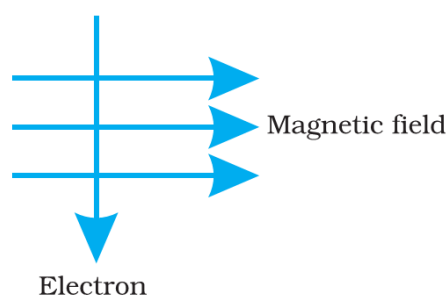
Force on a current-carrying conductor in a magnetic field

- Electric current flowing through a conductor produces a magnetic field.
- The field so produced exerts a force on a magnet placed in the vicinity of the conductor.
- French scientist Andre Marie Ampere (1775-1836) suggested that the magnet must also exert an equal and opposite force on the current-carrying conductor.
- The direction of the force on the conductor depends upon the direction of current and the direction of the magnetic field.
- The direction of the force on the conductor can be found by applying **Fleming's left-hand rule**.



- According to this rule, stretch the thumb, forefinger and middle finger of your left hand such that they are mutually perpendicular.
- If the first finger points in the direction of magnetic field and the second finger in the direction of current, then the thumb will point in the direction of motion or the force acting on the conductor.
- Devices that use current-carrying conductors and magnetic fields include electric motor, electric generator, loudspeakers, microphones and measuring instruments.
- When a current-carrying conductor is placed in a magnetic field such that the direction of current is perpendicular to the magnetic field, it experiences a force. This force causes the conductor to move.

Q. An electron enters a magnetic field at right angles to it. The direction of force acting on the electron will be



- a) to the right.
- b) to the left.
- c) out of the page.
- d) into the page.
- Answer is option (d). The direction of force is perpendicular to the direction of magnetic field and current as given by Fleming's left hand rule. Recall that the direction of current is taken opposite to the direction of motion of electrons. The force is therefore directed into the page.

Q. Which of the following property of a proton can change while it moves freely in a magnetic field?

(There may be more than one correct answer.)

- a) mass
- b) speed
- c) velocity
- d) momentum

Ans: Velocity of the proton (+ve charge = direction of current) increases and hence its momentum (momentum = mass x velocity).

Q. A positively-charged particle (alpha-particle) projected towards west is deflected towards north by a magnetic field. The direction of magnetic field is

- a) towards south
- b) towards east
- c) downward
- d) upward

Direction of current (middle finger) is towards west.

The direction of force (thumb) is towards north.

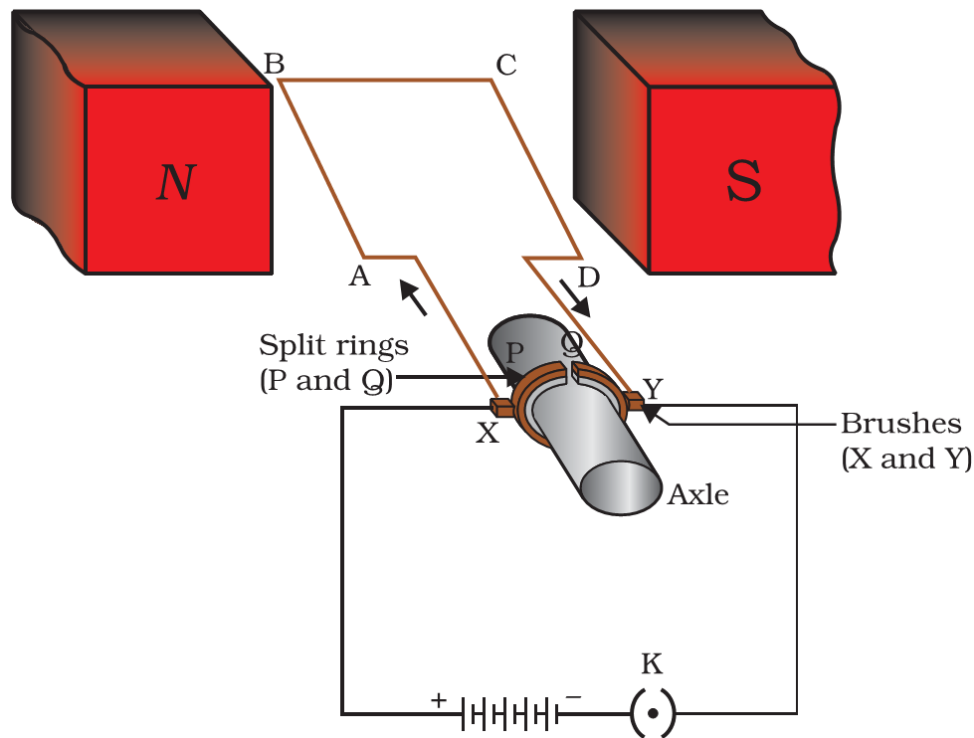
According to Fleming's left hand rule, the direction of magnetic field (index finger) will be *d) upwards*.

Magnetism in medicine

- An electric current always produces a magnetic field.
- Even weak ion currents that travel along the nerve cells in our body produce magnetic fields.
- When we touch something, our nerves carry an electric impulse to the muscles we need to use. This impulse produces a **temporary magnetic field**.
- These fields are very weak and are about one-billionth of the earth's magnetic field.
- Two main organs in the human body where the magnetic field produced is significant, are **the heart and the brain**.
- The magnetic field inside the body forms the basis of obtaining the images of different body parts.
- This is done using a technique called **Magnetic Resonance Imaging (MRI)**.
- Analysis of these images helps in medical diagnosis. Magnetism has, thus, got important uses in medicine.

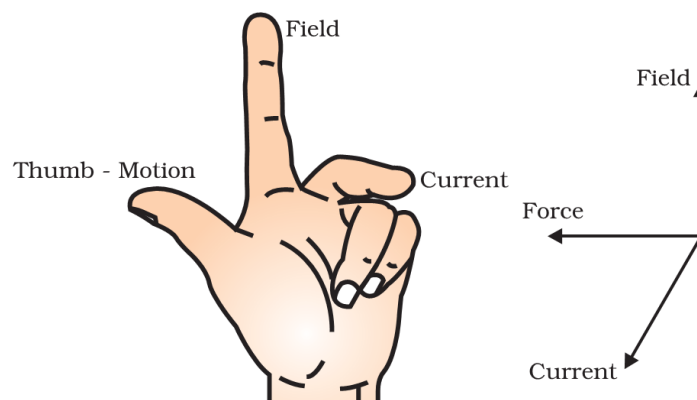
Electric motor

- An electric motor is a rotating device that converts electrical energy to mechanical energy.
- An electric motor consists of a rectangular coil ABCD of insulated copper wire.
- The coil is placed between the two poles of a magnetic field.

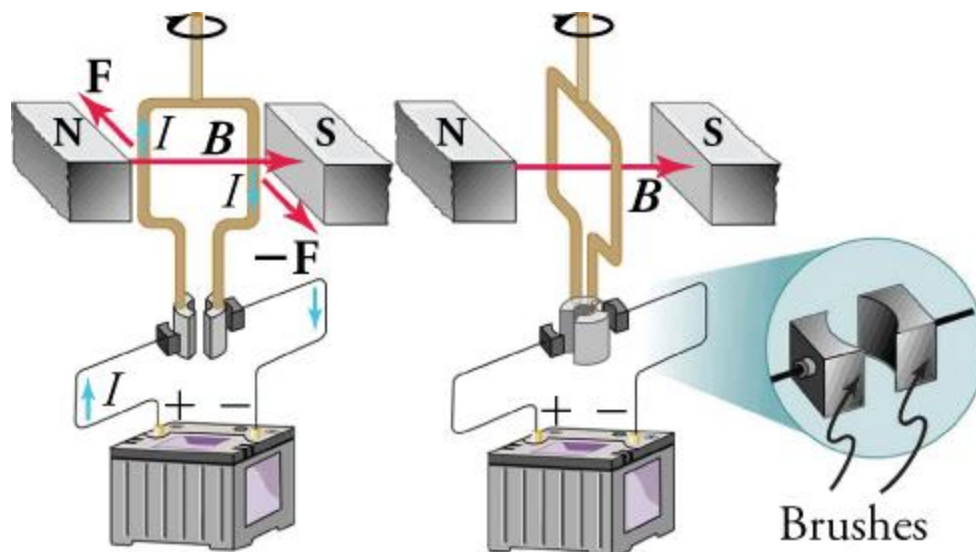


A simple electric motor

- The ends of the coil are connected to the two halves of a split ring (P and Q).
- The inner sides of these halves are insulated and attached to an axle.
- The external conducting edges of P and Q touch two conducting **stationary brushes** X and Y, respectively.
- Current in the coil ABCD enters through conducting brush X and flows back to the battery through brush Y.
- That is, the current in arm AB flows from A to B. In arm CD it flows from C to D.



- On applying Fleming's left hand rule, we find that the force acting on arm AB pushes it downwards while the force acting on arm CD pushes it upwards. Thus, the coil and the axle rotate anti-clockwise.
- At half rotation, Q makes contact with the brush X, and P with **brush Y**.

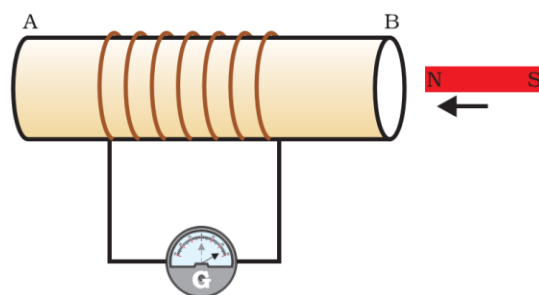


- Therefore, the **current in the coil gets reversed** and flows along the path DCBA.
- A device that reverses the direction of flow of current through a circuit is called a **commutator**.
- In electric motors, the **split ring acts as a commutator**.
- The reversal of current also reverses the direction of force acting on the two arms AB and CD.
- Thus, the arm AB of the coil that was earlier pushed down is now pushed up and the arm CD previously pushed up is now pushed down.
- Therefore, the coil and the axle rotate half a turn more in the same direction.
- **The reversing of the current is repeated at each half rotation**, giving rise to a continuous rotation of the coil and to the axle.
- The commercial motors use
 - a) an **electromagnet** in place of permanent magnet;
 - b) large number of turns of the conducting wire in the current carrying coil; and
 - c) a soft iron core on which the coil is wound.
- The soft iron core, on which the coil is wound, plus the coils, is called an **armature**. This enhances the power of the motor.

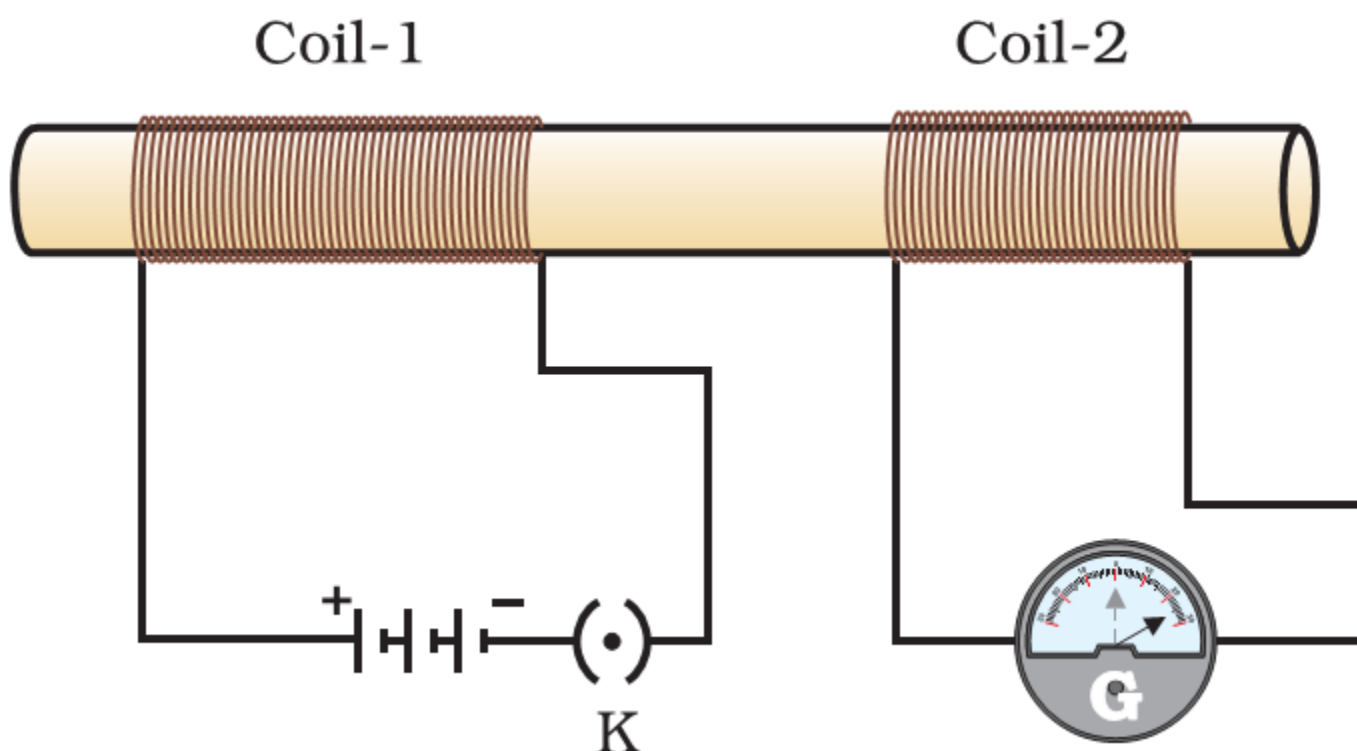
Electromagnetic induction

- A **galvanometer** is an instrument that can detect the presence of a current in a circuit.
- The pointer remains at zero (the centre of the scale) for zero current flowing through it.

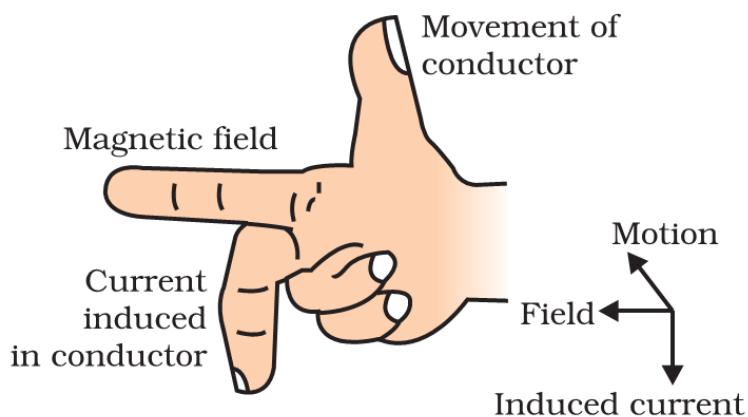
- It can deflect either to the left or to the right of the zero mark depending on the direction of current.



- Let us imagine a situation in which a magnet's north pole is moving towards end B of the conductor coil.
- There is a momentary deflection in the needle of the galvanometer.
- This indicates the presence of a current in the coil AB.
- The deflection becomes zero the moment the motion of the magnet stops.
- If the south pole of the magnet is moved towards the end B of the coil, the deflections in the galvanometer would just be opposite to the previous case.
- It is, thus, clear from this activity that motion of a magnet with respect to the coil produces an **induced potential difference**, which sets up an induced electric current in the circuit.
- This phenomenon was first studied by English physicist Michael Faraday. In 1831, Faraday made an important breakthrough by discovering how a moving magnet can be used to generate electric currents.
- Let us now replace the moving magnet by a current-carrying coil and the current in the coil can be varied.



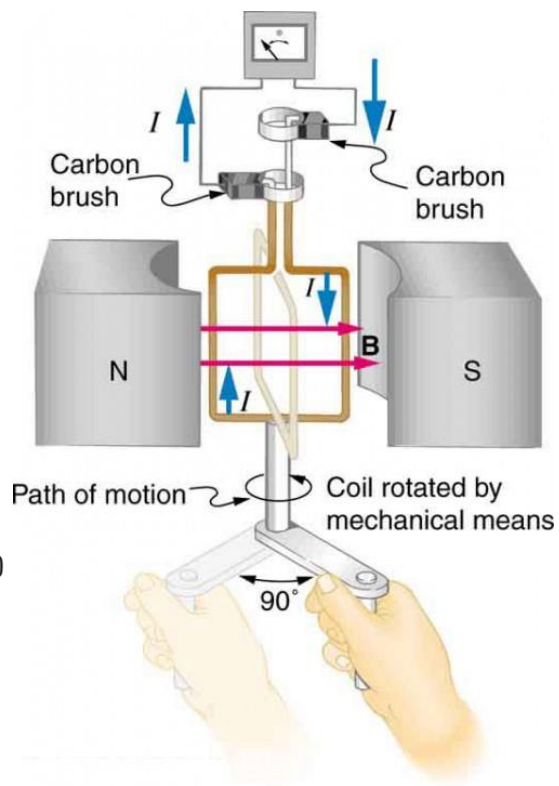
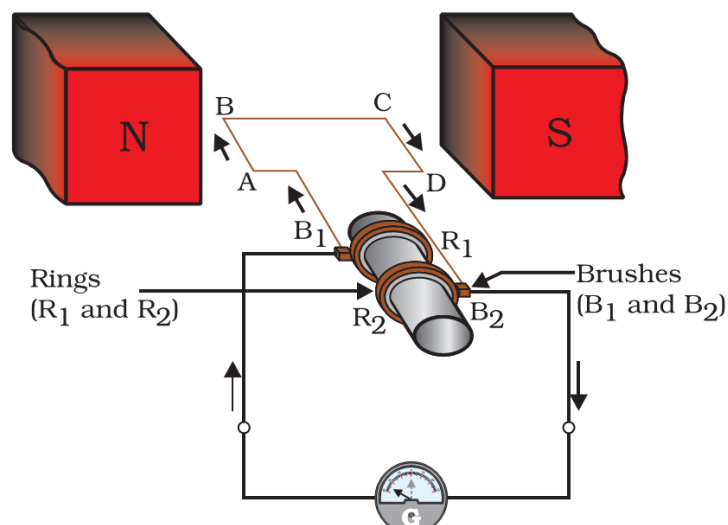
- Coil-1 is called the primary coil and coil-2 is called the secondary coil. As the current in the first coil changes, the magnetic field associated with it also changes.
- Thus, the magnetic field lines around the secondary coil also change.
- Hence the change in magnetic field lines associated with the secondary coil is the cause of induced electric current in it.
- This process, by which a **changing magnetic field in a conductor induces a current in another conductor**, is called **electromagnetic induction**.
- In practice we can induce current in a coil either by moving it in a magnetic field or by changing the magnetic field around it. It is convenient in most situations to move the coil in a magnetic field.
- The induced current is found to be the highest when the direction of motion of the coil is at right angles to the magnetic field.
- In this situation, we can use a simple rule to know the direction of the induced current: Stretch the thumb, forefinger and middle finger of right hand so that they are perpendicular to each other.
- If the forefinger indicates the direction of the magnetic field and the thumb shows the direction of motion of conductor, then the middle finger will show the direction of induced current. This simple rule is called **Fleming's right-hand rule**.



Michael Faraday (1791-1867)

- Michael Faraday was an experimental physicist. He had no formal education.
- Faraday made several path-breaking discoveries that include electromagnetic induction and the laws of electrolysis.

Electric generator



- Electromagnetic induction is also employed to produce large currents for use in homes and industry.
- In an electric generator, a conductor is rotated in a magnetic field to produce electricity.
- An electric generator consists of a rotating rectangular coil ABCD placed between the **two poles of a permanent magnet**.
- The two ends of this coil are connected to the two rings R1 and R2.
- The inner side of these rings are insulated.
- The two conducting stationary brushes B1 and B2 are kept pressed separately on the rings R1 and R2, respectively.
- The two rings R1 and R2 are internally attached to an axle.
- The axle may be mechanically rotated from outside to rotate the coil inside the magnetic field.
- Outer ends of the two brushes are connected to the galvanometer to show the flow of current in the circuit.
- The axle attached to the two rings is rotated such that the arm AB moves up (and the arm CD moves down) in the magnetic field produced by the permanent magnet (ABCD is rotated clockwise).
- By applying Fleming's right-hand rule, the induced currents are set up in these arms along the directions AB and CD.
- Thus, an induced current flows in the direction ABCD.
- This means that the current in the external circuit flows from B2 to B1.
- If there are larger numbers of turns in the coil, the current generated in each turn adds up to give a large current through the coil.

- After half a rotation, arm CD starts moving up and AB moving down. As a result, the directions of the induced currents in both the arms change, giving rise to the net induced current in the direction DCBA.
- The current in the external circuit now flows from B1 to B2.
- Thus, after every half rotation the polarity of the current in the respective arms changes.
- Such a current, which changes direction after equal intervals of time, is called an alternating current (abbreviated as AC). This device is called an **AC generator**.
- To get a direct current (DC, which does not change its direction with time), a **split-ring type commutator** must be used. The generator is thus called a **DC generator**.
- The difference between the direct and alternating currents is that the direct current always flows in one direction, whereas the alternating current reverses its direction periodically.
- Most power stations constructed these days produce AC.
- In India, the AC changes direction after every 1/100 second, that is, the frequency of AC is **50 Hz**.
- An important advantage of AC over DC is that electric power can be **transmitted over long distances without much loss of energy**.

Q. A rectangular coil of copper wires is rotated in a magnetic field. The direction of the induced current changes once in each

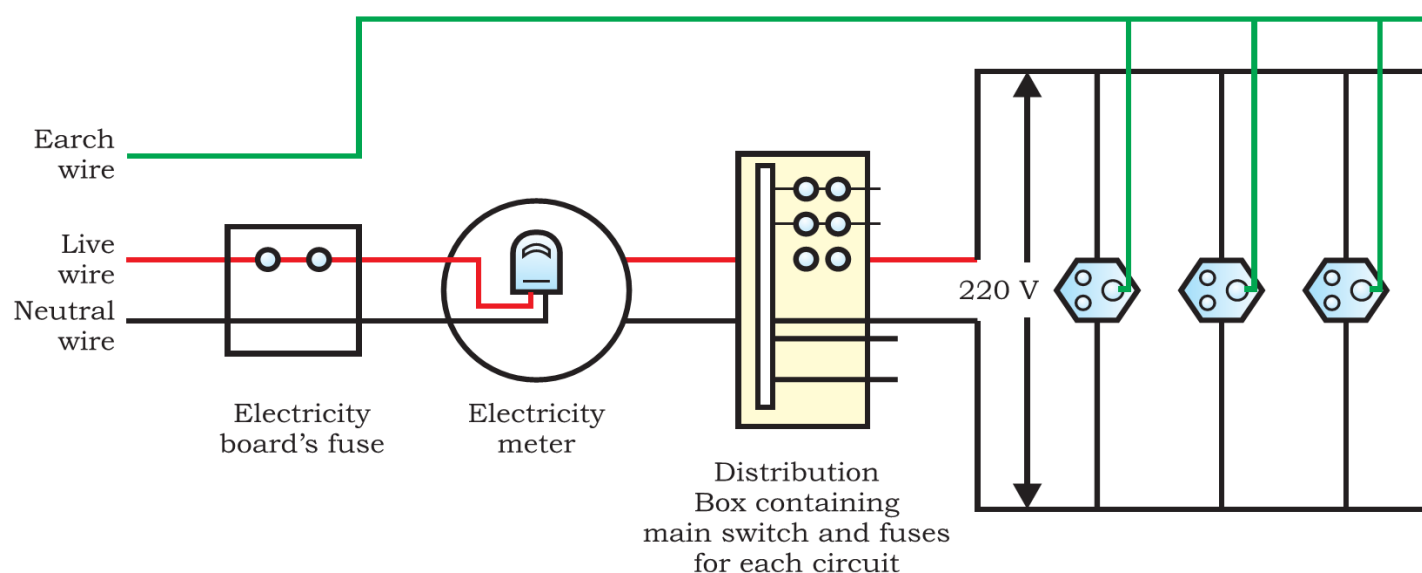
- a) two revolutions
- b) one revolution
- c) half revolution
- d) one-fourth revolution

Answer: 1/2

Domestic electric circuits

- In our homes, one of the wires in the supply, usually with red insulation cover, is called live wire (or positive).
- Another wire, with black insulation, is called neutral wire (or negative).
- In our country, the potential difference between the two is **220 V. (220 V and 50 Hz AC current)**
- At the metre-board in the house, these wires pass into an electricity meter through a main fuse.
- Often, two separate circuits are used, one of 15 A current rating for appliances with higher power ratings such as geysers, air coolers, etc.
- The other circuit is of 5 A current rating for bulbs, fans, etc.

- The earth wire, which has insulation of green colour, is usually connected to a metal plate deep in the earth near the house.
- This is used as a safety measure, especially for those appliances that have a metallic body, for example, electric press, toaster, table fan, refrigerator, etc.
- The metallic body is connected to the earth wire, which provides a low-resistance conducting path for the current.
- Thus, it ensures that any leakage of current to the metallic body of the appliance keeps its potential to that of the earth, and the user may not get a severe electric shock.



A schematic diagram of one of the common domestic circuits

- Electric fuse is an important component of all domestic circuits. A fuse in a circuit prevents damage to the appliances and the circuit due to overloading.
- Overloading can occur when the live wire and the neutral wire come into direct contact. (This occurs when the insulation of wires is damaged or there is a fault in the appliance.)
- In such a situation, the current in the circuit abruptly increases. This is called short-circuiting.
- The use of an electric fuse prevents the electric circuit and the appliance from a possible damage by stopping the flow of unduly high electric current.
- The Joule heating that takes place in the fuse melts it to break the electric circuit.
- Overloading can also occur due to an accidental hike in the supply voltage. Sometimes overloading is caused by connecting too many appliances to a single socket.

Summary

- An electromagnet consists of a core of soft iron wrapped around with a coil of insulated copper wire.
- A current-carrying conductor when placed in a magnetic field experiences a force. If the direction of the field and that of the current are mutually perpendicular to each other, then the force acting on the conductor will be perpendicular to both and will be given by **Fleming's left-hand rule**. This is the basis of an **electric motor**.
- The phenomenon of **electromagnetic induction** is the production of **induced current in a coil** placed in a region where the magnetic field changes with time. If the coil is placed near to a current-carrying conductor, the magnetic field may change either due to a change in the current through the conductor or due to the relative motion between the coil and conductor. The direction of the induced current is given by the **Fleming's right-hand rule**.
- In our houses we receive AC electric power of 220 V with a frequency of 50 Hz.

Q. Which of the following correctly describes the magnetic field near a long straight wire?

- a) The field consists of straight lines perpendicular to the wire.
- b) The field consists of straight lines parallel to the wire.
- c) The field consists of radial lines originating from the wire.
- d) The field consists of concentric circles centred on the wire.

Q. The phenomenon of electromagnetic induction is

- a) the process of charging a body.
- b) the process of generating magnetic field due to a current passing through a coil.
- c) producing induced current in a coil due to relative motion between a magnet and the coil.
- d) the process of rotating a coil of an electric motor.

Q. The essential difference between an AC generator and a DC generator is that

- a) AC generator has an electromagnet while a DC generator has permanent magnet.
- b) DC generator will generate a higher voltage.
- c) AC generator will generate a higher voltage.
- d) AC generator has slip rings while the DC generator has a commutator.

Answer: option four

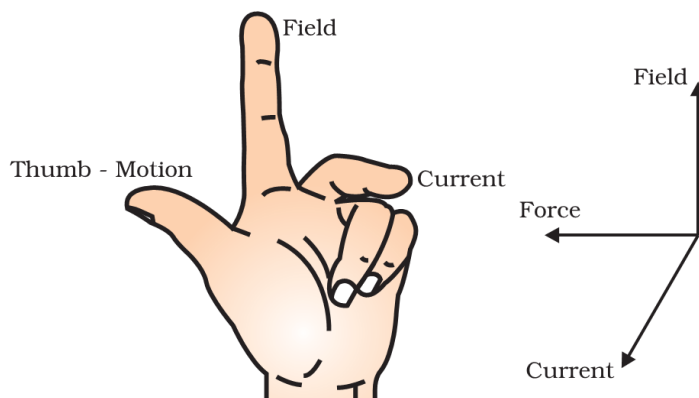
Q. When is the force experienced by a current-carrying conductor placed in a magnetic field largest?

- Ans: when the magnetic field and electric current are perpendicular to each other (**Fleming's left-hand rule**).

Q. Imagine that you are sitting in a chamber with your back to one wall. An electron beam moving horizontally from back wall towards the front wall, is deflected by a strong magnetic field to your right side.

What is the direction of magnetic field?

- Ans: An electron beam moving horizontally from back wall towards the front wall == electric flowing from front wall towards back wall (Middle Finger).
- Is deflected by a strong magnetic field to your right side (thumb)
- Direction of magnetic field (index finger) = downwards direction (**Fleming's left-hand rule**).



Q. State the rule to determine the direction of a

- magnetic field produced around a straight conductor-carrying current (**Right-Hand Thumb Rule**),
- force experienced by a current-carrying straight conductor placed in a magnetic field which is perpendicular to it (**Fleming's left-hand rule**), and
- current induced in a coil due to its rotation in a magnetic field (**Fleming's right-hand rule**).

Electric Motor → Fleming's left-hand rule

Electric Generator → Electromagnetic Induction → Fleming's right-hand rule

3. Motion

- When objects move along a straight line it is called rectilinear motion.
- Motion of a pendulum and motion on strings of a guitar are examples of periodic motion.
- In periodic motion an object repeats its motion after a fixed interval of time.
- Galileo Galilie (A.D. 1564 –1642) discovered that the **time period of a given pendulum is constant**. That is, a pendulum of a given length takes always the same time to complete one oscillation.
- This observation led to the development of pendulum clocks.

3.1 Force

- Forces applied on an object in the same direction add to one another.
- If the two forces act in the opposite directions on an object, the net force acting on it is the difference between the two forces.

Contact Forces

- Muscular Force
- Friction: The frictional force exerted by fluids is also called drag.

Non-contact Forces

- These forces come into play even when the bodies are not in contact.
- Magnetic Force
- Electrostatic Force: The force exerted by a charged body on another charged or uncharged body is known as electrostatic force.
- Gravitational Force: This is an attractive force. The force of gravity acts on all objects.
- Pressure: The force acting on a unit area of a surface is called pressure.

Q. An inflated balloon was pressed against a wall after it has been rubbed with a piece of synthetic cloth. It was found that the balloon sticks to the wall. What force might be responsible for the attraction between the balloon and the wall?

Ans: Electrostatic Force

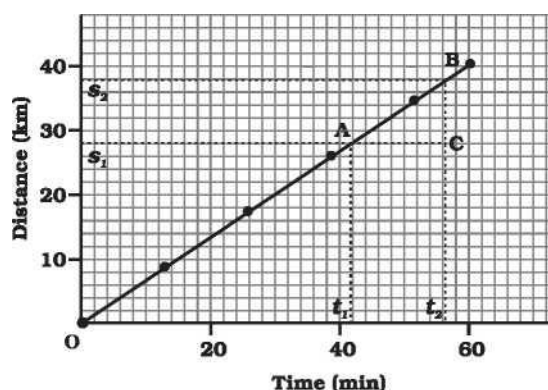
3.2 Friction

1. Rolling friction
 2. Sliding friction
 3. Static friction
- Friction opposes the relative motion between two surfaces in contact. It acts on both the surfaces.
 - Static friction comes into play when we try to move an object at rest.
 - Sliding friction comes with play when an object is sliding over another.
 - Sliding friction is smaller than static friction.
 - When one body rolls over another body, rolling friction comes into play. Rolling friction is smaller than the sliding friction.

3.3 Speed, Velocity & Acceleration

Speed

- Speed is the total distance covered divided by the total time taken.
- The SI unit of speed is metre per second. This is represented by the symbol ms^{-1} or m/s.
- If the speed of an object moving along a straight line keeps changing, its motion is said to be **non-uniform**.
- An object moving along a straight line with a constant speed is said to be in **uniform motion**.
- In the case of uniform motion, the average speed is the same as the actual speed.
- The distance-time graph an object moving with a constant speed (uniform motion) is a straight line.

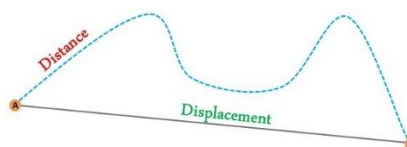


Distance-time graph of an object moving with uniform speed

- In most cases, objects will be in non-uniform motion. Therefore, we describe the rate of motion of such objects in terms of their average speed.
- The average speed of an object is obtained by dividing the total distance travelled by the total time taken.

Displacement

- The shortest distance measured from the initial to the final position of an object is known as the displacement.



- The magnitude of the displacement for a course of motion may be zero but the corresponding distance covered is not zero.
- If the final position of the object coincides with the initial position, the displacement is zero.
- E.g. If you complete one revolution on a circular track then the distance travelled is equal to $2\pi r$, but the displacement is zero.

Velocity: Speed with direction

- The rate of motion of an object can be more comprehensive if we specify its direction of motion along with its speed. The quantity that specifies both these aspects is called velocity.
- Velocity is the speed of an object moving in a definite direction.
- The velocity of an object can be uniform or variable.
- It can be changed by changing the object's speed, direction of motion or both.
- When an object is moving along a straight line at a variable speed, we can express the magnitude of its rate of motion in terms of **average velocity**. It is calculated in the same way as we calculate average speed.
- In case the velocity of the object is **changing at a uniform rate**, then average velocity is given by the **arithmetic mean of initial velocity and final velocity** for a given period of time. That is, initial velocity + final velocity = average velocity.

$$\text{Average speed} = \frac{\text{Total distance covered}}{\text{Total time taken}}$$

$$\text{Average velocity} = \frac{\text{Displacement}}{\text{Total time taken}}$$

Acceleration: Rate of Change of Velocity

- During uniform motion of an object along a straight line, the velocity remains constant with time. In this case, the change in velocity of the object for any time interval is zero.
- However, in non-uniform motion, velocity varies with time. It has different values at different instants and at different points of the path. Thus, the change in velocity of the object during any time interval is not zero.
- Acceleration is a measure of the change in the velocity of an object per unit time.

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

- If the velocity of an object changes from an initial value u to the final value v in time t , the acceleration a is,

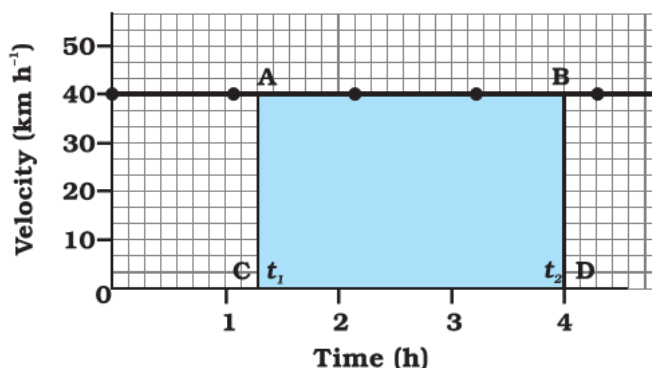
$$a = \frac{v - u}{t}$$

- This kind of motion is known as **accelerated motion**.

- The acceleration is taken to be positive if it is in the direction of velocity and negative when it is opposite to the direction of velocity. The SI unit of acceleration is ms^{-2} .
- If an object travels in a straight line and its velocity increases or decreases by equal amounts in equal intervals of time, then the acceleration of the object is said to be **uniform**.
- The **motion of a freely falling body** is an example of uniformly accelerated motion.
- On the other hand, an object can travel with non-uniform acceleration if its velocity changes at a non-uniform rate.

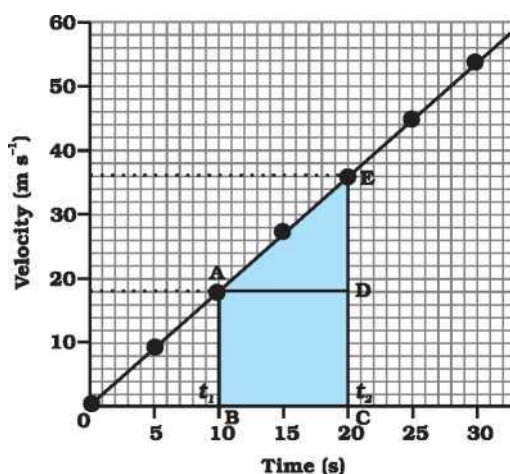
Velocity-time graphs

- If the object moves at uniform velocity, the height of its velocity-time graph will not change with time.
- It will be a straight line parallel to the x-axis.



Velocity-time graph for uniform motion of a car

- The area enclosed by velocity-time graph and the time axis will be equal to the magnitude of the displacement (product of velocity and time give displacement of an object moving with uniform velocity).



Velocity-time graph for a car moving with uniform accelerations.

- For all uniformly accelerated motion, the velocity-time graph is a straight line.

- The area under the velocity-time graph gives the distance (magnitude of displacement) moved by the car in a given interval of time.
- If the car would have been moving with **uniform velocity**, the distance travelled by it would be represented by the area ABCD under the graph.
- Since the magnitude of the velocity of the car is changing due to acceleration, the distance s travelled by the car will be given by the area ABCDE under the velocity-time graph.

Equations of Motion by Graphical Method

- When an object moves along a straight line with uniform acceleration, it is possible to relate its velocity, acceleration during motion and the distance covered by it in a certain time interval by a set of equations known as the equations of motion. There are three such equations. These are:

$$v = u + at$$

$$s = ut + \frac{1}{2} at^2$$

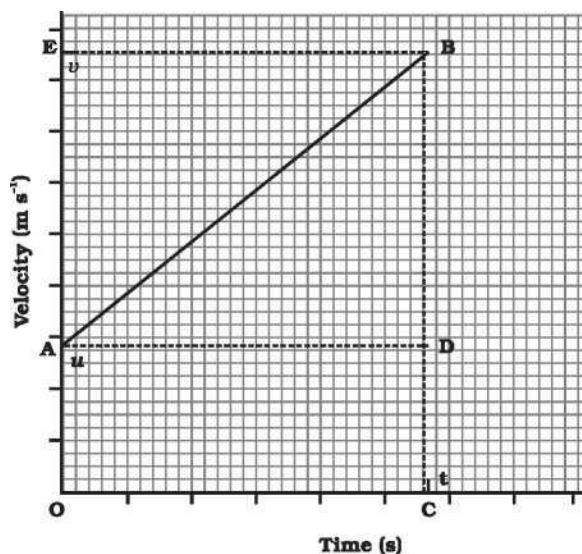
$$2as = v^2 - u^2$$

u is the initial velocity of the object which moves with uniform acceleration a for time t ,

v is the final velocity, and

s is the distance travelled by the object in time t .

Equation for velocity-time ($v = u + at$)



Velocity-time graph to obtain the equations of motion

- From this graph, you can see that initial velocity of the object is u (at point A) and then it increases to v (at point B) in time t . The velocity changes at a uniform rate a .

- The perpendicular lines BC and BE are drawn from point B on the time and the velocity axes respectively, so that the initial velocity is represented by OA, the final velocity is represented by BC and the time interval t is represented by OC. $BD = BC - CD$, represents the change in velocity in time interval t.
- Let us draw AD parallel to OC. From the graph, we observe that

$$BC = BD + DC = BD + OA$$

Substituting $BC = v$ and $OA = u$, we get $v = BD + u$ or **$BD = v - u$**

- From the velocity-time graph, the acceleration of the object is given by $a = \text{Change in velocity} / \text{time taken}$.

$$a = BD/AD = BD/OC$$

Substituting $OC = t$, we get

$$a = BD/t$$

$$\text{or } BD = at$$

$$\text{or } \mathbf{v - u = at}$$

Equation for position-time ($s = ut + \frac{1}{2} at^2$)

- Let us consider that the object has travelled a distance s in time t under uniform acceleration a.
- The distance travelled by the object is obtained by the area enclosed within OABC under the velocity-time graph AB.
- Thus, the distance s travelled by the object is given by

$$s = \text{area OABC (which is a trapezium)} = \text{area of the rectangle OADC} + \text{area of the triangle ABD}$$

$$s = OA \times OC + \frac{1}{2} (AD \times BD)$$

Substituting $OA = u$, $OC = AD = t$ and $BD = at$, we get

$$\mathbf{s = ut + \frac{1}{2} at^2}$$

Equation for position-velocity ($2 as = v^2 - u^2$)

- The distance s travelled by the object in time t, moving under uniform acceleration a is given by the area enclosed within the trapezium OABC under the graph. That is, $s = \text{area of the trapezium OABC}$

$$= (OA + BC) \times OC / 2$$

Substituting $OA = u$, $BC = v$ and $OC = t$, we get

$$s = (u + v) t / 2$$

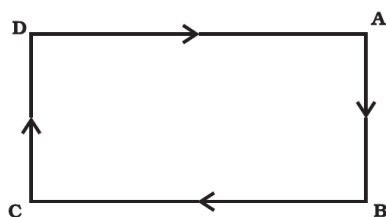
From the velocity-time relation, we get

$$t = (v - u) / a$$

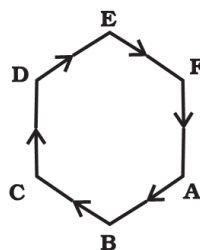
$$\text{thus, } s = (u + v) (v - u) / 2a$$

$$\text{or } 2as = v^2 - u^2$$

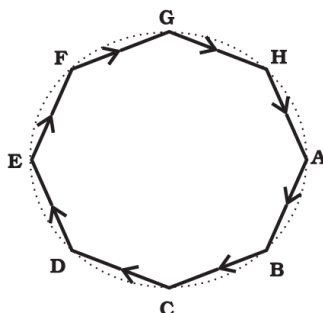
Uniform Circular Motion



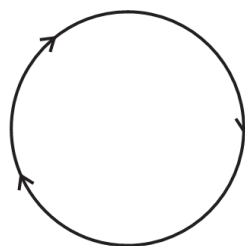
(a) Rectangular track



(b) Hexagonal track



(c) Octagonal shaped track



(d) A circular track

- Let us consider an example of the motion of a body along a closed path. Fig (a) shows the path of an athlete along a rectangular track ABCD.
- It is clear that to move in a rectangular track once, he has to change his direction of motion four times.
- Now, suppose instead of a rectangular track, the athlete is running along a hexagonal shaped path ABCDEF, as shown in Fig (b).
- In this situation, the athlete will have to change his direction six times while he completes one round.
- It is observed that as the number of sides of the track increases the athlete has to take turns more and more often.
- What would happen to the shape of the track as we go on increasing the number of sides indefinitely? If you do this, you will notice that the shape of the track approaches the shape of a circle and the length of each of the sides will decrease to a point.
- If the athlete moves with a velocity of constant magnitude along the circular path, the only change in his velocity is due to the change in the direction of motion.
- The motion of the athlete moving along a circular path is, therefore, an example of an accelerated motion.
- We know that the circumference of a circle of radius r is given by $2\pi r$.

- If the athlete takes t seconds to go once around the circular path of radius r , the velocity v is given by

$$v = 2\pi r / t$$

- When an object moves in a circular path with uniform speed, its motion is called **uniform circular motion**.

Q. State which of the following situations are possible and give an example for each of these:

- an object with a constant acceleration but with zero velocity (Ans: When an object is thrown upwards, at the maximum height, the velocity of the object becomes zero. However, the object is in constant acceleration due to gravity.)
- an object moving in a certain direction with an acceleration in the perpendicular direction. (Ans: Circular motion)

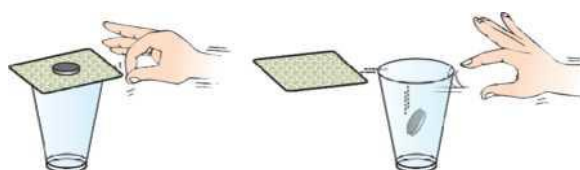
3.4 Newton's laws of motion

Balanced and Unbalanced Forces

- Balanced forces do not change the state of rest or of motion of an object.
- Unbalanced force acting on an object brings it in motion.
- Newton studied Galileo's ideas on force and motion and presented three fundamental laws that govern the motion of objects. These three laws are known as Newton's laws of motion.

First Law of Motion

- **An object remains in a state of rest or of uniform motion in a straight line unless compelled to change that state by an applied force.**
- It thus suggests that an unbalanced (external) force is required to change the motion of the object but no net force is needed to sustain the uniform motion of the object.
- In practical situations it is difficult to achieve a zero unbalanced force. This is because of the presence of the frictional force acting opposite to the direction of motion.
- In a qualitative way, the tendency of undisturbed objects to stay at rest or to keep moving with the same velocity is called **inertia (tendency to maintain the same state of motion)**.
- This is why, the first law of motion is also known as the **law of inertia**.



- Heavier or more massive objects offer larger inertia.
- Quantitatively, the inertia of an object is measured by its **mass**.

Second Law of Motion

- The first law of motion indicates that when an unbalanced external force acts on an object, its velocity changes, that is, the object gets an acceleration.
- We would now like to study how the acceleration of an object depends on the force applied to it and how we measure a force.
- A moving truck, even at low speeds, may kill a person standing in its path. A bullet may kill a person when fired from a gun.
- These observations suggest that the impact produced by the objects depends on their **mass and velocity**.
- In other words, there appears to exist some quantity of importance that combines the object's mass and its velocity. One such property called momentum was introduced by Newton.
- The momentum, p of an object is defined as the product of its mass, m and velocity, v . That is, **$p = mv$** .
- Momentum has both **direction and magnitude**. Its direction is the same as that of velocity, v .
- The SI unit of momentum is kilogram-metre per second (kg ms^{-1}).
- Since the application of an unbalanced force brings a change in the velocity of the object, it is therefore clear that a force also produces a change of momentum.
- **The second law of motion states that the rate of change of momentum of an object is proportional to the applied unbalanced force in the direction of force.**
- Suppose an object of mass, m is moving along a straight line with an initial velocity, u . It is uniformly accelerated to velocity, v in time, t by the application of a constant force, F throughout the time, t .
- The initial and final momentum of the object will be, $p_1 = mu$ and $p_2 = mv$ respectively.

The change in momentum, **$p_2 - p_1 \propto mv - mu = m(v - u)$**

The rate of change of momentum **$\propto m(v - u) / t$**

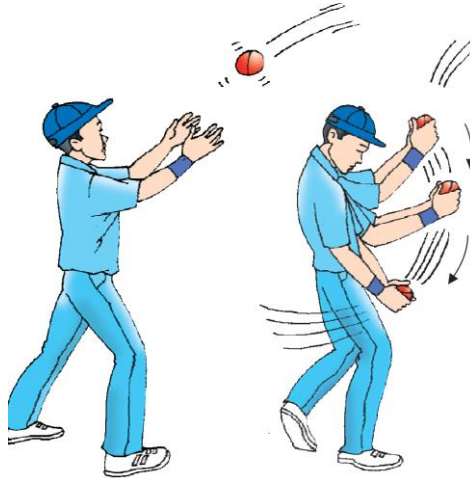
Or, the applied force, **$F \propto m(v - u) / t$**

$F = k m(v - u) / t$, where k is ratio of proportionality

$F = k ma$; because $(v - u) / t = a$

- The unit of force is so chosen that the value of the constant, k becomes one.
- For this, one unit of force is defined as the amount that produces an acceleration of 1 m s^{-2} in an object of 1 kg mass. That is, $1 \text{ unit of force} = k \times (1 \text{ kg}) \times (1 \text{ m s}^{-2})$.
- Thus, the value of k becomes 1 and **$F = ma$**

- The unit of force is **kgms⁻²** or **newton**, which has the symbol N.
- The second law of motion is often seen in action in our everyday life. Have you noticed that while catching a fast moving cricket ball, a fielder in the ground gradually pulls his hands backwards with the moving ball?
- In doing so, the fielder increases the time during which the high velocity of the moving ball decreases to zero.
- Thus, the acceleration of the ball is decreased and therefore the impact of catching the fast moving ball is also reduced.



- The first law of motion can be mathematically stated from the mathematical expression for the second law of motion.

$$F = ma$$

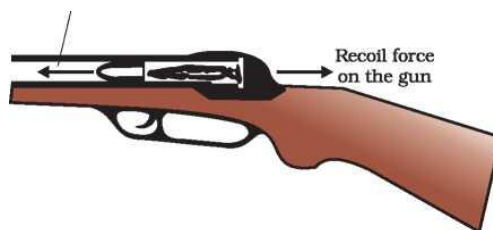
$$\text{or } Ft = mv - mu$$

- That is, when $F = 0$, $v = u$ for whatever time, t is taken. This means that the object will continue moving with uniform velocity, u throughout the time, t .
- If u is zero, then v will also be zero. That is, the object will remain at rest.

Third Law of Motion

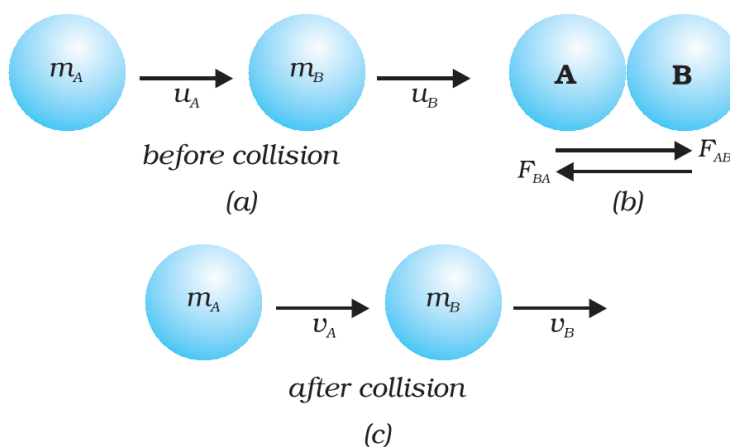
- The first two laws of motion tell us how an applied force changes the motion and provide us with a method of determining the force.
- **The third law of motion states that when one object exerts a force on another object, the second object instantaneously exerts a force back on the first.**
- These two forces are always equal in magnitude but opposite in direction. These forces act on different objects and never on the same object.

- When a gun is fired, it exerts a forward force on the bullet. The bullet exerts an equal and opposite reaction force on the gun. This results in the recoil of the gun.
- Since the gun has a much greater mass than the bullet, the acceleration of the gun is much less than the acceleration of the bullet.



Conservation of Momentum

- **The sum of momenta of the two objects before collision is equal to the sum of momenta after the collision provided there is no external unbalanced force acting on them. This is known as the law of conservation of momentum.**
- Suppose two objects (two balls A and B, say) of masses m_A and m_B are travelling in the same direction along a straight line at different velocities u_A and u_B , respectively.
- And there are no other external unbalanced forces acting on them.
- Let $u_A > u_B$ and the two balls collide with each other as shown in Fig.
- During collision which lasts for a time t , the ball A exerts a force F_{AB} on ball B and the ball B exerts a force F_{BA} on ball A.
- v_A and v_B are the velocities of the two balls A and B after the collision, respectively.



- The momenta (plural of momentum) of ball A before and after the collision are $m_A u_A$ and $m_A v_A$, respectively. The rate of change of its momentum (or F_{AB} , action) during the collision will be $m_A (v_A - u_A) / t$

- Similarly, the rate of change of momentum of ball B (= F_{BA} or reaction) during the collision will be $m_B (v_B - u_B) / t$
- According to the third law of motion, the force F_{AB} exerted by ball A on ball B (action) and the force F_{BA} exerted by the ball B on ball A (reaction) must be equal and opposite to each other. Therefore,

$$F_{AB} = - F_{BA}$$

$$m_A (v_A - u_A) / t = - [m_B (v_B - u_B) / t]$$

$$\text{this gives, } m_A u_A + m_B u_B = m_A v_A + m_B v_B$$

that is,

- Since $(m_A u_A + m_B u_B)$ is the total momentum of the two balls A and B before the collision and $(m_A v_A + m_B v_B)$ is their total momentum after the collision, we observe that the total momentum of the two balls remains unchanged or conserved provided no other external force acts.

Conservation laws

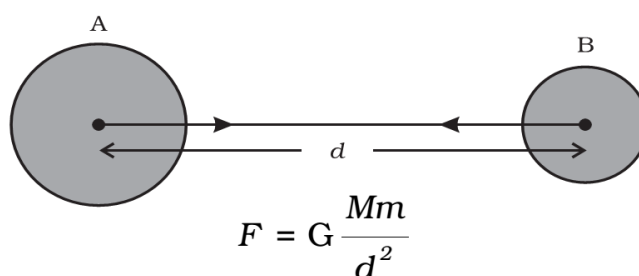
- All conservation laws such as conservation of momentum, energy, angular momentum, charge etc. are considered to be fundamental laws in physics. These are based on observations and experiments.
- It is important to remember that a conservation law cannot be proved. It can be verified, or disproved, by experiments.
- An experiment whose result is in conformity with the law verifies or substantiates the law; it does not prove the law.
- On the other hand, a single experiment whose result goes against the law is enough to disprove it.
- The law of conservation of momentum has been deduced from large number of observations and experiments. This law was formulated nearly three centuries ago.
- It is interesting to note that not a single situation has been realised so far, which contradicts this law. Several experiences of every-day life can be explained on the basis of the law of conservation of momentum.

3.5 Gravitation

- The motion of the moon around the earth is due to the centripetal force.
- The centripetal force is provided by the force of attraction of the earth.
- If there were no such force, the moon would pursue a uniform straight line motion.
- Newton concluded that all objects in the universe attract each other. This force of attraction between objects is called the gravitational force.

Universal law of gravitation

- **Every object in the universe attracts every other object with a force which is proportional to the product of their masses and inversely proportional to the square of the distance between them. The force is along the line joining the centres of two objects.**
- A and B of masses M and m lie at a distance d from each other.
- Let the force of attraction between two objects be F .
- According to the universal law of gravitation, the force between two objects is directly proportional to the product of their masses.
- And the force between two objects is inversely proportional to the square of the distance between them.



- G is the constant of proportionality and is called the **universal gravitation constant**.

Why the earth doesn't move towards the apple?

- According to the second law of motion, for a given force, **acceleration is inversely proportional to the mass of an object**.
- The mass of an apple is negligibly small compared to that of the earth. So, we do not see the earth moving towards the apple.

Isaac Newton (1642 - 1727)

- He invented a new branch of mathematics, called calculus. He used it to prove that for objects outside a sphere of uniform density, the sphere behaves as if the whole of its mass is concentrated at its centre.
- Newton transformed the structure of physical science with his three laws of motion and the universal law of gravitation.
- How did Newton guess the inverse-square rule?
- Johannes Kepler derived three laws that govern the motion of planets. These are called Kepler's laws.
- It is important to note that Kepler could not give a theory to explain the motion of planets.
- It was Newton who showed that the cause of the planetary motion is the gravitational force that the Sun exerts on them. Newton used the third law of Kepler to calculate the gravitational force of attraction.

- The SI unit of G can be obtained by substituting the units of force, distance and mass as $\text{N m}^2 \text{kg}^{-2}$.
- The value of G was found out by Henry Cavendish (1731 - 1810) by using a sensitive balance. The accepted value of G is **$6.673 \times 10^{-11} \text{ N m}^2 \text{kg}^{-2}$** .

Acceleration due to gravity

- Whenever an object falls towards the earth, an acceleration is involved. This acceleration is due to the earth's gravitational force.
- Therefore, this acceleration is called the acceleration due to the gravitational force of the earth (or acceleration due to gravity). It is denoted by g . The unit of g is the same as that of acceleration, that is, ms^{-2} .

$$m g = G \frac{M \times m}{d^2}$$

$$\text{or} \quad g = G \frac{M}{d^2}$$

M is the mass of the earth, and d is the distance between the object and the earth.

Let an object be on or near the surface of the earth. The distance d will be equal to R , the radius of the earth.

Thus, for objects on or near the surface of the earth

$$m g = G \frac{M \times m}{R^2}$$

$$g = G \frac{M}{R^2}$$

- To calculate the value of g ,

universal gravitational constant, $G = 6.7 \times 10^{-11} \text{ N m}^2 \text{kg}^{-2}$,

mass of the earth, $M = 6 \times 10^{24} \text{ kg}$, and

radius of the earth, $R = 6.4 \times 10^6 \text{ m}$.

$$\begin{aligned} g &= G \frac{M}{R^2} \\ &= \frac{6.7 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 6 \times 10^{24} \text{ kg}}{(6.4 \times 10^6 \text{ m})^2} \\ &= 9.8 \text{ m s}^{-2}. \end{aligned}$$

- The earth is not a perfect sphere. As the radius of the earth increases from the poles to the equator, the value of g becomes **greater at the poles than at the equator**.

Mass and weight

Mass

- The mass of an object is the measure of its inertia. Greater the mass, the greater is the inertia.
- It remains the same whether the object is on the earth, the moon or even in outer space.
- Thus, the mass of an object is constant and does not change from place to place.

Weight

- We know that the earth attracts every object with a certain force and this force depends on the mass (m) of the object and the acceleration due to the gravity (g).
- The weight of an object is the force with which it is attracted towards the earth.
- As the weight of an object is the force with which it is attracted towards the earth, the SI unit of weight is the same as that of force, that is, newton (N).
- The weight is a force acting vertically downwards; it has both magnitude and direction.
- We have learnt that the value of g is constant at a given place. Therefore, at a given place, the weight of an object is directly proportional to the mass, say m , of the object, that is, $W = m \times g$.
- It is due to this reason that at a given place, we can use the weight of an object as a measure of its mass.
- The **mass of an object remains the same everywhere**, that is, on the earth and on any planet whereas its **weight depends on its location**.

Thrust and Pressure

- The force acting on an object perpendicular to the surface is called thrust.
- When you stand on loose sand, the force, that is, the weight of your body is acting on an area equal to area of your feet. When you lie down, the same force acts on an area equal to the contact area of your whole body, which is larger than the area of your feet. Thus, the effects of forces of the same magnitude on different areas are different.

- Therefore, the effect of thrust depends on the area on which it acts.
- The **thrust on unit area is called pressure**. SI unit of pressure is **N/m^2 or N m^{-2}** .
- In honour of scientist Blaise Pascal, the SI unit of pressure is called **pascal, denoted as Pa**.
- All liquids and gases are fluids. A solid exerts pressure on a surface due to its weight. Similarly, fluids have weight, and they also exert pressure on the base and walls of the container in which they are enclosed.
- Pressure exerted in any confined mass of fluid is transmitted undiminished in all directions.

Buoyancy

- Push an empty bottle into the water. You feel an upward push.
- This indicates that water exerts a force on the bottle in the upward direction. The upward force exerted by the water goes on increasing as the bottle is pushed deeper till it is completely immersed.
- The upward force exerted by the water on the bottle is known as **upthrust or buoyant force**.
- In fact, all objects experience a force of buoyancy when they are immersed in a fluid.
- The magnitude of this buoyant force depends on the **density of the fluid**.
- The nail sinks because the downward force acting on the nail is greater than the upthrust of water.



An iron nail sinks and a cork floats when placed on the surface of water.

- The cork floats while the nail sinks. This happens because of the difference in their densities.
- The density of a substance is defined as the **mass per unit volume**.
- The density of cork is less than the density of water.
- This means that the upthrust of water on the cork is greater than the weight of the cork. So, it floats.

Archimedes' principle

- Archimedes was a Greek scientist. He discovered the principle, subsequently named after him, after noticing that the water in a bathtub overflowed when he stepped into it.
- This knowledge helped him to determine the purity of the gold in the crown made for the king.

- His work in the field of Geometry and Mechanics made him famous. His understanding of levers, pulleys, wheels- and-axle helped the Greek army in its war with Roman army.
- Archimedes' principle has many applications. It is used in designing ships and submarines.
- **Lactometers**, which are used to determine the purity of a sample of milk and **hydrometers** used for determining density of liquids, are based on this principle.

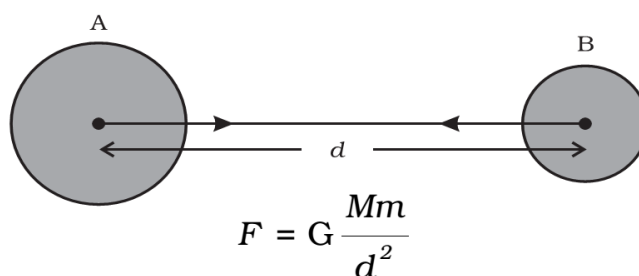
Relative Density

- The density of a substance is defined as mass of a unit volume.
- The unit of density is kilogram per metre cube (kg m^{-3}).
- The density of a given substance, under specified conditions, remains the same.
- It is different for different substances. For example, the density of gold is 19300 kg m^{-3} while that of water is 1000 kg m^{-3} .
- **The density of a given sample of a substance can help us to determine its purity.**
- It is often convenient to express density of a substance in comparison with that of water.
- The relative density of a substance is the ratio of its density to that of water:

Q. Gravitational force acts on all objects in proportion to their masses. Why then, a heavy object does not fall faster than a light object?

- Gravitational force acts on all objects in proportion to their masses.
- But a heavy object does not fall faster than a light object.
- This is because of the reason that $\text{Acceleration} = \text{Force} / \text{Mass}$ or $\text{Force} = \text{Acceleration} \times \text{Mass}$.
- As force is directly proportional to mass, **acceleration is constant for a body of any mass.**

Q. The earth and the moon are attracted to each other by gravitational force. Does the earth attract the moon with a force that is greater or smaller or the same as the force with which the moon attracts the earth? Why?



- M = Mass of earth, m = Mass of moon, d = Distance between the earth and the moon.
- The magnitude of force (F) is mutual and hence it is same for the earth and the moon.

3.6 Work and Energy

- Two conditions need to be satisfied for work to be done: (i) a force should act on an object, and (ii) the object must be displaced.
- If any one of the above conditions does not exist, work is not done.
- **Work done = force x displacement**
- Here the unit of work is newton metre (**N m**) or joule (**J**).
- The work done by a force can be either positive or negative.
- Work done is negative when the force acts opposite to the direction of displacement.
- Work done is positive when the force is in the direction of displacement.

Forms of energy

- The energy possessed by an object is measured in terms of its capacity of doing work.
- The unit of energy is, therefore, the same as that of work, that is, joule (J).
- 1 J is the energy required to do 1 joule of work.
- Sometimes a larger unit of energy called kilo joule (kJ) is used. 1 kJ equals 1000 J.
- The various forms include potential energy, kinetic energy, heat energy, chemical energy, electrical energy and light energy.

James Prescott Joule

- James Prescott Joule was an outstanding British physicist. He is best known for his research in electricity and thermodynamics. Amongst other things, he formulated a law for the heating effect of electric current.
- He also verified experimentally the law of conservation of energy and discovered the value of the mechanical equivalent of heat. The unit of energy and work called joule, is named after him.
- A moving object can do work. An object moving faster can do more work than an identical object moving relatively slow.

Kinetic energy of an object

- **Objects in motion possess energy. We call this energy kinetic energy.**
- A falling coconut, a speeding car, etc. possess kinetic energy.
- In short, kinetic energy is the **energy possessed by an object due to its motion.**
- The kinetic energy of an object increases with its speed.

- By definition, we say that the kinetic energy of a body moving with a certain velocity is equal to the **work done on it to make it acquire that velocity**.
- Consider an object of mass, m moving with a uniform velocity, u . Let it now be displaced through a distance s when a constant force, F acts on it in the direction of its displacement. Work done, $\mathbf{W = Fs}$.
- The work done on the object will cause a change in its velocity.
- Let its velocity change from u to v . Let a be the acceleration produced.
- The relation connecting the initial velocity (u) and final velocity (v) of an object moving with a uniform acceleration a , and the displacement, s is $v^2 - u^2 = 2a s$
- This gives

$$s = \frac{v^2 - u^2}{2a}$$

$$W = m a \times \left(\frac{v^2 - u^2}{2a} \right)$$

or

$$W = \frac{1}{2} m (v^2 - u^2)$$

- If the object is starting from its stationary position, that is, $u = 0$, then

$$W = \frac{1}{2} m v^2$$

- It is clear that the **work done is equal to the change in the kinetic energy of an object**.
- If $u = 0$, the work done will be $(1/2) m v^2$.
- Thus, the kinetic energy possessed by an object of mass, m and moving with a uniform velocity, v is

$$E_k = \frac{1}{2} m v^2$$

Potential energy of an object

- An object increases its energy when raised through a height. This is because work is done on it against gravity while it is being raised. The energy present in such an object is the gravitational potential energy.
- The gravitational potential energy of an object at a point above the ground is defined as the **work done in raising it from the ground to that point against gravity**.
- It is easy to arrive at an expression for the gravitational potential energy of an object at a height.

- Consider an object of mass, m . Let it be raised through a height, h from the ground. A force is required to do this. The minimum force required to raise the object is equal to the weight of the object, mg ($F = ma$).
- The object gains energy equal to the work done on it. Let the work done on the object against gravity be W . That is, work done, **$W = \text{force} \times \text{displacement} = mg \times h = mgh$**
- Since work done on the object is equal to mgh , an energy equal to mgh units is gained by the object. This is the **potential energy ($E_p = mgh$)**.

Law of conservation of energy

- **Whenever energy gets transformed, the total energy remains unchanged. This is the law of conservation of energy.**
- According to this law, energy can only be converted from one form to another; it can **neither be created or destroyed**. The total energy before and after the transformation remains the same.
- The law of conservation of energy is valid in all situations and for all kinds of transformations.
- That is, **potential energy + kinetic energy = constant**
- The **sum of kinetic energy and potential energy of an object is its total mechanical energy**.
- We find that during the free fall of the object, the decrease in potential energy, at any point in its path, appears as an equal amount of increase in kinetic energy.
- There is thus a continual transformation of gravitational potential energy into kinetic energy.

Power: Rate of Doing Work

- Power measures the speed of work done, that is, how fast or slow work is done.
- Power is defined as the rate of doing work or the rate of transfer of energy.
- If an agent does a work W in time t , then power is given by:
- **Power = work done / time taken = W/t**
- The unit of power is **watt** [in honour of James Watt (1736 - 1819)] having the symbol W .
- 1 watt is the power of an agent, which does work at the rate of 1 joule per second. We can also say that power is 1 W when the rate of consumption of energy is 1 J s^{-1} .
- $1 \text{ watt} = 1 \text{ joule/second}$ or $1 \text{ W} = 1 \text{ J s}^{-1}$. We express larger rates of energy transfer in kilowatts (kW).
- **1 kilowatt = 1000 watts 1 kW = 1000 W 1 kW = 1000 J s^{-1}** .

Commercial unit of energy

- The unit joule is too small and hence is inconvenient to express large quantities of energy. We use a bigger unit of energy called kilowatt hour (kW h).

- What is 1 kW h? Let us say we have a machine that uses 1000 J of energy every second. If this machine is used continuously for one hour, it will consume 1 kW h of energy.
- Thus, 1 kW h is the energy used in one hour at the rate of 1000 J s⁻¹ (or 1 kW).
- **1 kW h = 1 kW x 1 h = 1000 W x 3600 s = 3600000 J 1 kW h = 3.6 x 10⁶ J.**
- The energy used in households and commercial establishments are usually expressed in **kilowatt hour**.
- For example, electrical energy used during a month is expressed in terms of '**units**'.
- Here, **1 'unit' means 1 kilowatt hour**.

Q. An object thrown at a certain angle to the ground moves in a curved path and falls back to the ground. The initial and the final points of the path of the object lie on the same horizontal line. What is the work done by the force of gravity on the object?

Q. A certain household has consumed 250 units of energy during a month. How much energy is this in joules?

$$1 \text{ kW h} = 1 \text{ kW} \times 1 \text{ h} = 1000 \text{ W} \times 3600 \text{ s} = 3600000 \text{ J} \quad 1 \text{ kW h} = 3.6 \times 10^6 \text{ J}$$

$$250 \text{ units} = 250 \times 3.6 \times 10^6 \text{ J}$$

- What is the work done by the force of gravity on a satellite moving round the earth? Justify your answer.
- Q. Can there be displacement of an object in the absence of any force acting on it? (Ans: Yes, e.g. an object moving in space outside the gravitational influence of any object. E.g. a rocket that escapes earth's gravity will keep moving without the requirement of any force.)

Facts

- The meter that measures the distance moved by the vehicle is known as an **odometer**.
- The time-keeping services in India are provided by the National Physical Laboratory, New Delhi.
- The clock they use can measure time intervals with an accuracy of one-millionth of a second.
- The most accurate clock in the world has been developed by the National Institute of Standards and Technology in the U.S.A. This clock will lose or gain one second after running for 20 million years.

4. Sound

4.1 Propagation of Sound

- The matter or substance through which sound is transmitted is called a medium.
- Sound travels through a medium (gas, liquid or solid). It **cannot travel in vacuum**.

The disturbance created by a source of sound in the medium travels through the medium and not the particles of the medium.

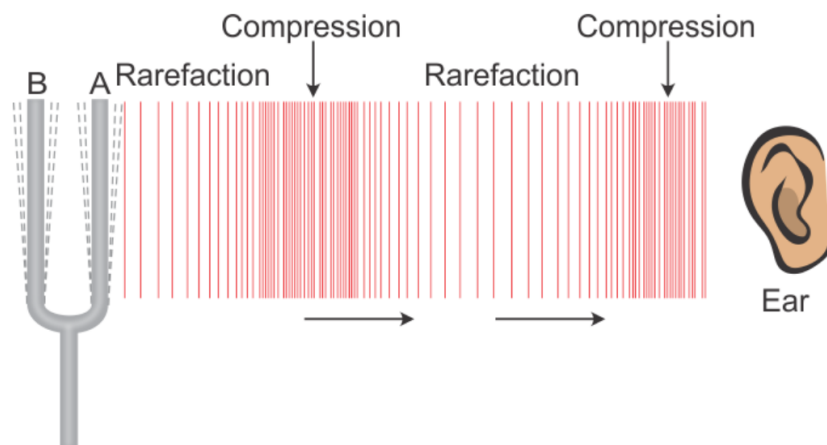
- When an object vibrates, it sets the particles of the medium around it vibrating.
- The particles do not travel all the way from the vibrating object to the ear.
- A particle of the medium in contact with the vibrating object is first displaced from its equilibrium position.
- It then exerts a force on the adjacent particle.
- As a result of which the adjacent particle gets displaced from its position of rest.
- After displacing the adjacent particle, the first particle comes back to its original position.
- This process continues in the medium till the sound reaches your ear.

Wave nature of sound

- Sound waves are characterised by the motion of particles in the medium and are called **mechanical waves**.
- In these waves the **individual particles of the medium move** in a **direction parallel to the direction of propagation of the disturbance**.
- The particles do not move from one place to another, but they simply oscillate back and forth about their position of rest. This is exactly how a sound wave propagates, hence sound waves are **longitudinal waves**.

- There is also another type of wave, called a **transverse wave**.
- In a transverse wave particle do not oscillate along the line of wave propagation but oscillate up and down about their mean position as the wave travels.
- Thus, a transverse wave is the one in which the individual particles of the medium move about their mean positions in a **direction perpendicular to the direction of wave propagation**.
- **Light is a transverse wave** but for light, the oscillations are not of the medium particles or their pressure or density - it is **not a mechanical wave**.

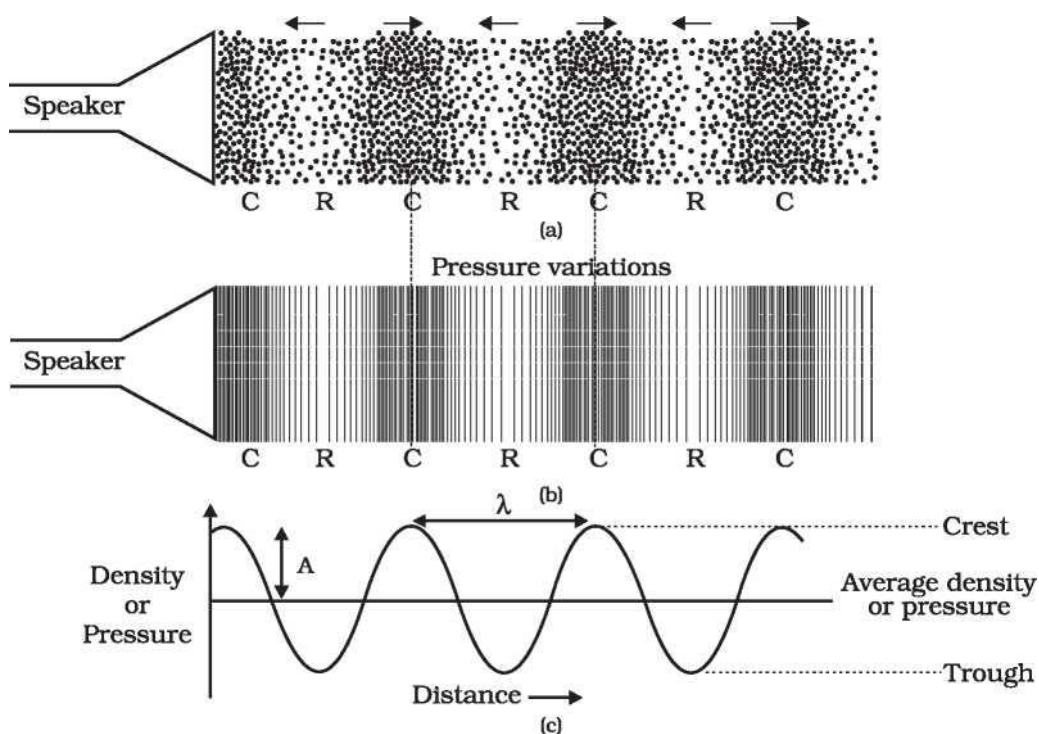
- Air is the most common medium through which sound travels.
- When a vibrating object moves forward, it pushes and compresses the air in front of it creating a region of high pressure. This region is called a **compression (C)**.
- This compression starts to move away from the vibrating object. When the vibrating object moves backwards, it creates a region of low pressure called **rarefaction (R)**.
- As the object moves back and forth rapidly, a series of compressions and rarefactions is created in the air.



- These make the sound wave that propagates through the medium. **Compression is the region of high pressure** and **rarefaction is the region of low pressure**.
- Pressure is related to the number of particles of a medium in a given volume.
- More density of the particles in the medium gives more pressure and vice versa.
- Thus, propagation of sound can be visualised as **propagation of density variations or pressure variations** in the medium.

4.2 Characteristics of a sound wave

- We can describe a sound wave by its
 - ✓ frequency
 - ✓ amplitude and
 - ✓ speed.



Sound propagates as density or pressure variations as shown in (a) and (b), (c) represents graphically the density and pressure variations.

Wavelength

- The distance between two consecutive compressions (C) or two consecutive rarefactions (R) is called the wavelength.
- The wavelength is usually represented by λ (Greek letter lambda). Its SI unit is metre (m).
- He also discovered the photoelectric effect which was later explained by Albert Einstein.

Frequency

Frequency of A Vibration

- We have learnt that the to and fro motion of an object is known as vibration.
 - This motion is also called **oscillatory motion or periodic motion**.
 - The **number of oscillations per second is called the frequency of oscillation**.
 - Frequency is expressed in **hertz**. Its symbol is Hz.
 - A frequency of 1 Hz is one oscillation per second.
- Heinrich Rudolph Hertz confirmed J.C. Maxwell's electromagnetic theory by his experiments. He laid the foundation for future development of radio, telephone, telegraph and even television.
- We know that when sound is propagated through a medium, the density of the medium oscillates between a maximum value and a minimum value.

- The change in density from the maximum value to the minimum value, again to the maximum value, makes one complete oscillation.
- The **number of such oscillations per unit time is the frequency of the sound wave**.
- If we can count the number of the compressions or rarefactions that cross us per unit time, we will get the frequency of the sound wave.
- A sound of single frequency is called a **tone**.
- The sound which is produced due to a mixture of several frequencies is called a **note**.

Audible and Inaudible Sounds

- Sounds of frequencies **less than about 20 vibrations per second (20 Hz) cannot be detected by the human ear**. Such sounds are called inaudible.
- On the higher side, **sounds of frequencies higher than about 20,000 vibrations per second (20 kHz) are also not audible** to the human ear.
- Thus, for human ear, the range of audible frequencies is roughly from **20 to 20,000 Hz**.

Infrasonic Sound or Infrasound

- Sounds of **frequencies below 20 Hz** are called infrasonic sound or **infrasound**.
- If we could hear infrasound, we would hear the vibrations of a pendulum just as we hear the vibrations of the wings of a bee.
- Rhinoceroses communicate using infrasound of frequency as low as 5 Hz.
- Whales and elephants produce sound in the infrasound range.
- It is observed that some animals get disturbed before earthquakes.
- Earthquakes produce **low-frequency infrasound** before the main shock waves begin which possibly alert the animals.

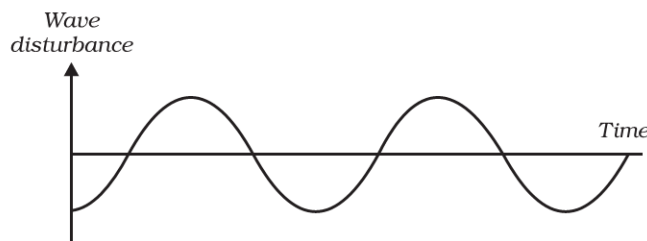
Ultrasonic sound or ultrasound

- Frequencies higher than 20 kHz are called **ultrasonic sound or ultrasound**.
- Ultrasound is produced by dolphins, bats and porpoises.
- Some animals can hear sounds of frequencies higher than 20,000 Hz. Dogs have this ability.
- The police use high frequency whistles which dogs can hear but humans cannot.
- Moths of certain families have very sensitive hearing equipment.
- These moths can hear the high frequency squeaks of the bat and know when a bat is flying nearby and are able to escape capture.

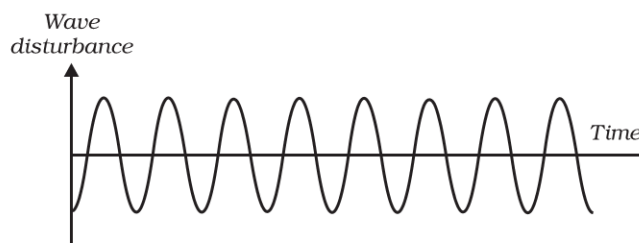
- Rats also play games by producing ultrasound.

Pitch

- How the brain interprets the frequency of an emitted sound is called the pitch.
- The **frequency determines the shrillness or pitch of a sound**.
- If the frequency of vibration is higher, we say that the sound is shrill and has a higher pitch.
- If the frequency of vibration is lower, we say that the sound has a lower pitch.



Wave shape for a low pitched sound



Wave shape for a high pitched sound

- Objects of different sizes and conditions vibrate at different frequencies to produce sounds of different pitch.
- For example, a drum vibrates with a low frequency. Therefore, it produces a low-pitched sound.
- On the other hand, a whistle has a high frequency and therefore, produces a sound of higher pitch.
- A bird makes a high-pitched sound whereas a lion makes a low-pitched roar.
- However, the roar of a lion is very loud while the sound of the bird is quite feeble.
- Usually the voice of a woman has a higher frequency and is shriller than that of a man.

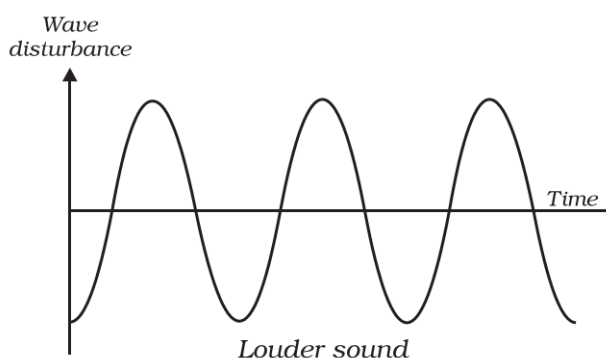
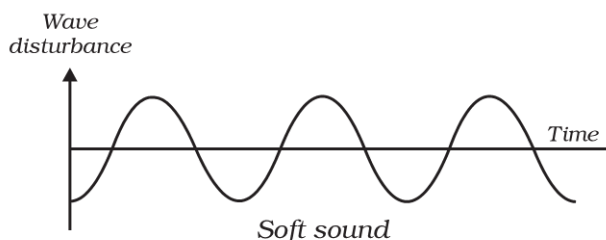
Time Period

- The **time taken by two consecutive compressions or rarefactions to cross a fixed point** is called the time period of the wave.
- In other words, we can say that the time taken for one complete oscillation in the density of the medium is called the time period of the sound wave.
- It is represented by the symbol T . Its SI unit is second (s).

- Frequency and time period are related as follows: Frequency (ν) = $1 / \text{Time Period (T)}$ = $1 / T$

Amplitude

- The **magnitude of the maximum disturbance in the medium on either side of the mean value** is called the amplitude of the wave. It is usually represented by the letter A.
- The loudness or softness of a sound is determined basically by its amplitude.



Loudness

- The loudness of sound depends on its amplitude.
- When the amplitude of vibration is large, the sound produced is loud.
- When the amplitude is small, the sound produced is feeble.
- Loudness of sound is proportional to the square of the amplitude of the vibration** producing the sound.
- For example, if the amplitude becomes twice, the loudness increases by a factor of 4.
- The **loudness is expressed in a unit called decibel (dB)**.

Normal breathing	10 dB
Soft whisper (at 5m)	30 dB
Normal conversation	60 dB
Busy traffic	70 dB
Average factory	80 dB

- Above 80 dB the noise becomes physically painful.**

- The amount of sound energy passing each second through unit area is called the **intensity of sound**.
- We sometimes use the terms "loudness" and "intensity" interchangeably, but they are not the same.
- Loudness is a measure of the response of the ear to the sound.
- Even when two sounds are of equal intensity, we may hear one as louder than the other simply because our ear detects it better.

Speed of Sound

- The speed of sound depends on the properties of the medium through which it travels.
- **The speed of sound decreases when we go from solid to gaseous state.**
- The speed of sound in a medium depends also on **temperature and pressure** of the medium.
- **In any medium as we increase the temperature the speed of sound increases.**
- For example, the speed of sound in air is 331 ms^{-1} at 0°C and 344 ms^{-1} at 22°C .

Sonic boom

- **When the speed of any object exceeds the speed of sound it is said to be travelling at supersonic speed.** Bullets, jet aircrafts etc. often travel at supersonic speeds.
- When a sound, producing source moves with a speed higher than that of sound, it produces **shock waves** in air. These shock waves carry a large amount of energy.
- The air pressure variation associated with this type of shock waves produces a very sharp and loud sound called the "**sonic boom**".
- The shock waves produced by a supersonic aircraft have enough energy to shatter glass and even damage buildings.

Reflection of Sound

- Sound bounces off a solid or a liquid like a rubber ball bounces off a wall.
- Like light, sound gets reflected at the surface of a solid or liquid and follows the same laws of reflection.
- The directions in which the sound is incident and is reflected make equal angles with the normal to the reflecting surface, and the three are in the same plane.

Echo

- If we shout or clap near a suitable reflecting object such as a tall building or a mountain, we will hear the same sound again a little later. This sound which we hear is called an echo.
- The sensation of **sound persists in our brain for about 0.1 s**.

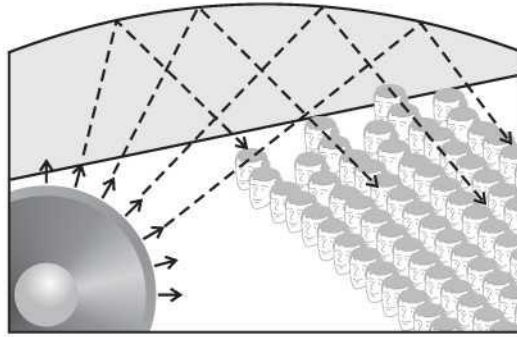
- **To hear a distinct echo the time interval between the original sound and the reflected one must be at least 0.1s.**
- If we take the speed of sound to be 344 m/s at a given temperature, say at 22 °C in air, the sound must go to the obstacle and reach back the ear of the listener on reflection after 0.1s.
- **Hence, the total distance covered by the sound from the point of generation to the reflecting surface and back should be at least $(344 \text{ m/s}) \times 0.1 \text{ s} = 34.4 \text{ m}$.**
- **Thus, for hearing distinct echoes, the minimum distance of the obstacle from the source of sound must be half of this distance, that is, 17.2 m.**
- This distance will **change with the temperature of air**.
- Echoes may be heard more than once due to successive or multiple reflections.
- **The rolling of thunder is due to the successive reflections of the sound** from a number of reflecting surfaces, such as the clouds and the land.

Reverberation

- A sound created in a big hall will persist by repeated reflection from the walls until it is reduced to a value where it is no longer audible.
- The repeated reflection that results in this persistence of sound is called reverberation.
- In an auditorium or big hall excessive reverberation is highly undesirable.
- To reduce reverberation, the roof and walls of the auditorium are generally covered with sound-absorbent materials like compressed fibreboard, rough plaster or draperies.
- The seat materials are also selected on the basis of their sound absorbing properties.
- In instruments, a tube followed by a conical opening reflects sound successively to guide most of the sound waves from the source in the forward direction towards the audience.

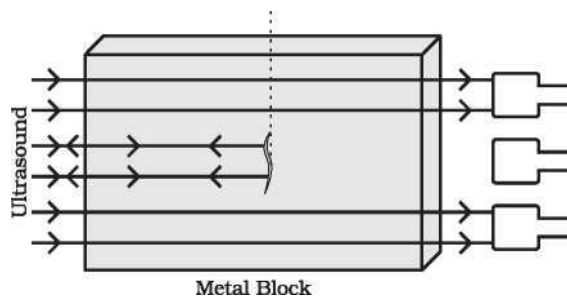
Why are the ceilings of concert halls curved?

- Generally, the ceilings of concert halls, conference halls and cinema halls are curved so that sound after reflection reaches all corners of the hall.
- Sometimes a curved soundboard may be placed behind the stage so that the sound, after reflecting from the sound board, spreads evenly across the width of the hall.



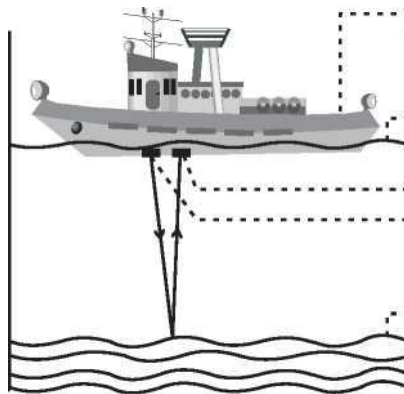
4.3 Applications of Ultrasound

- The **ultrasound** equipment, familiar to us for investigating and tracking many medical problems, works at **frequencies higher than 20,000 Hz**.
- **Ultrasounds are able to travel along well-defined paths even in the presence of obstacles.**
- Ultrasound is generally used to clean parts located in hard-to-reach places, for example, spiral tube, odd shaped parts, electronic components etc.
- Due to the high frequency, the particles of dust, grease and dirt get detached and drop out. The objects thus get thoroughly cleaned.
- **A technician uses ultrasound to remove water drops in a mobile phone or an electronic gadget that fell in water.**
- Ultrasounds can be used to detect cracks and flaws in metal blocks. Metallic components are generally used in construction of big structures like buildings, bridges, machines and also scientific equipment.
- The cracks or holes inside the metal blocks, which are invisible from outside reduces the strength of the structure.
- Ultrasonic waves are allowed to pass through the metal block and detectors are used to detect the transmitted waves.
- If there is even a small defect, the ultrasound gets reflected back indicating the presence of the flaw or defect.



Ultrasound is reflected back from the defective locations inside a metal block.

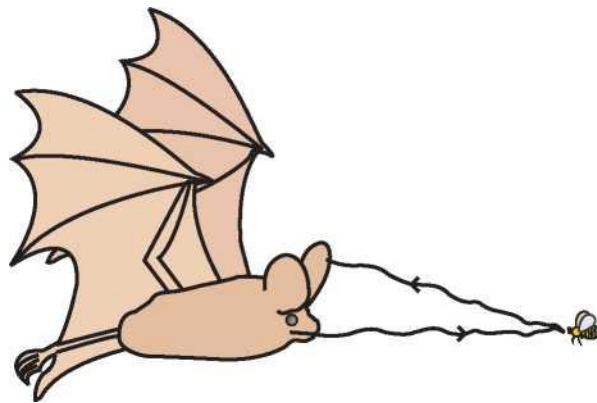
- Ordinary sound of longer wavelengths cannot be used for such purpose as it will bend around the corners of the defective location and enter the detector.
- Ultrasonic waves are made to reflect from various parts of the heart and form the image of the heart. This technique is called '**echocardiography**'.
- Ultrasound scanner is an instrument which uses ultrasonic waves for getting images of internal organs of the human body. A doctor may image the patient's organs such as the liver, gall bladder, uterus, kidney, etc.
- It helps the doctor to detect abnormalities, such as stones in the gall bladder and kidney or tumours in different organs.
- In this technique the ultrasonic waves travel through the tissues of the body and get reflected from a region where there is a change of tissue density.
- These waves are then converted into electrical signals that are used to generate images of the organ.
- These images are then displayed on a monitor or printed on a film. This technique is called '**ultrasonography**'.
- Ultrasonography is also used for examination of the foetus during pregnancy **to detect congenital defects and growth abnormalities**.
- Ultrasound may be employed **to break small 'stones' formed in the kidneys** into fine grains. These grains later get flushed out with urine.



- Ultrasound sent by the transmitter and received by the detector.
- The transmitter produces and transmits ultrasonic waves. These waves travel through water and after striking the object on the seabed, get reflected back and are sensed by the detector.
- The detector converts the ultrasonic waves into electrical signals which are appropriately interpreted.
- The distance of the object that reflected the sound wave can be calculated by knowing the speed of sound in water and the time interval between transmission and reception of the ultrasound.
- The above method is called **echo-ranging**.

Sonar

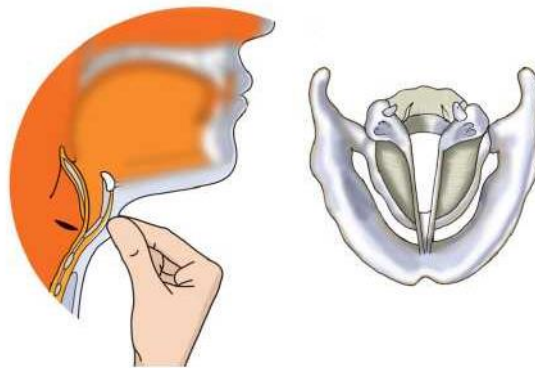
- The **sonar technique is used to determine the depth of the sea and to locate underwater hills, valleys, submarine, icebergs, sunken ship etc.**
- The acronym SONAR stands for **Sound Navigation and Ranging**.
- Sonar is a device that uses **ultrasonic waves** to measure the distance, direction and speed of underwater objects.
- Sonar consists of a transmitter and a detector and is installed in a boat or a ship.
- Bats search out prey and fly in dark night by emitting and detecting reflections of ultrasonic waves.
- The high-pitched ultrasonic squeaks of the bat are reflected from the obstacles or prey and returned to bat's ear.
- The nature of reflections tells the bat where the obstacle or prey is and what it is like.
- Porpoises also use ultrasound for navigation and location of food in the dark.



Ultrasound is emitted by a bat and it is reflected back by the prey or an obstacle.

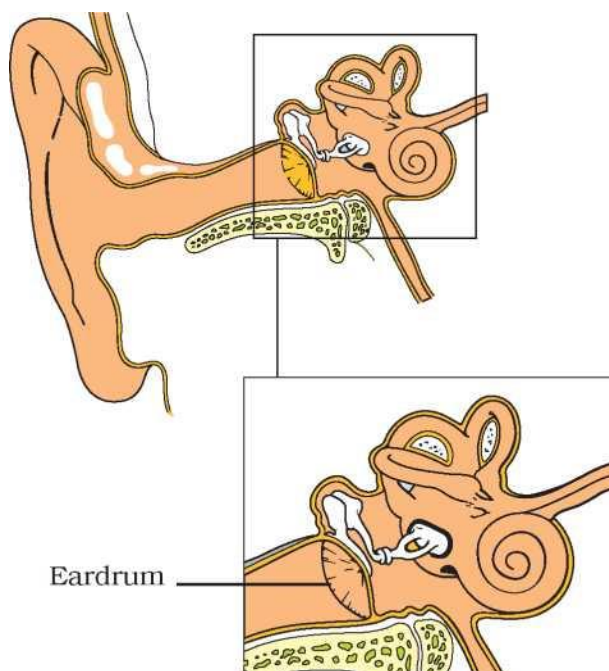
Voice box

- In humans, the sound is produced by the voice box or the larynx. It is at the upper end of the windpipe.
- Two vocal cords, are stretched across the voice box or larynx in such a way that it leaves a narrow slit between them for the passage of air



Voice box in humans

- When the lungs force air through the slit, the vocal cords vibrate, producing sound.
- Muscles attached to the vocal cords can make the cords tight or loose.
- When the vocal cords are tight and thin, the type or quality of voice is different.
- The vocal cords in men are about 20mm long. In women these are about 5mm shorter. Children have very short vocal cords.
- This is the reason why the voices of men, women and children are different.
- The shape of the outer part of the ear is like a funnel. When sound enters in it, it travels down a canal at the end of which a thin membrane is stretched tightly. It is called the eardrum.
- The eardrum is like a stretched rubber sheet. Sound vibrations make the eardrum vibrate. The eardrum sends vibrations to the inner ear. From there, the signal goes to the brain. That is how we hear.



Did You Know

- Golconda fort, near Hyderabad, is famous for many engineering and architectural marvels.

- One of the marvels is the water supply system.
- But, perhaps, more astonishing is a dome near the entrance to the fort.
- A hand-clap at a particular point under the dome reverberates and can be heard at the highest point of the fort, about a kilometre away. This was devised as a warning system.

5. Heat

- A reliable measure of the hotness of an object is its temperature.
- Temperature is measured by a device called thermometer.
- The normal temperature of human body is 37°C .
- The temperature of human body normally does not go below **35°C or above 42°C** .
- That is the reason that clinical thermometers have the range 35°C to 42°C .
- The range of a laboratory thermometer is generally from -10°C to 110°C .
- Why does the mercury not fall or rise in a clinical thermometer when taken out of the mouth? Ans: The kink in the thermometer bulb prevents mercury level from falling on its own.



Transfer of heat

- In solids, generally, the heat is transferred by the process of conduction.
- The materials which allow heat to pass through them easily are conductors of heat.
- The materials which do not allow heat to pass through them easily are poor conductors of heat such as plastic and wood. Poor conductors are known as insulators.
- The water and air are poor conductors of heat. Walls constructed using hollow bricks are better at insulating the house as the trapped air is a bad conductor of heat.
- The mode of heat transfer in a pot of boiling water is known as convection.
- [Land and sea breeze](#) are examples of convection on a large scale.

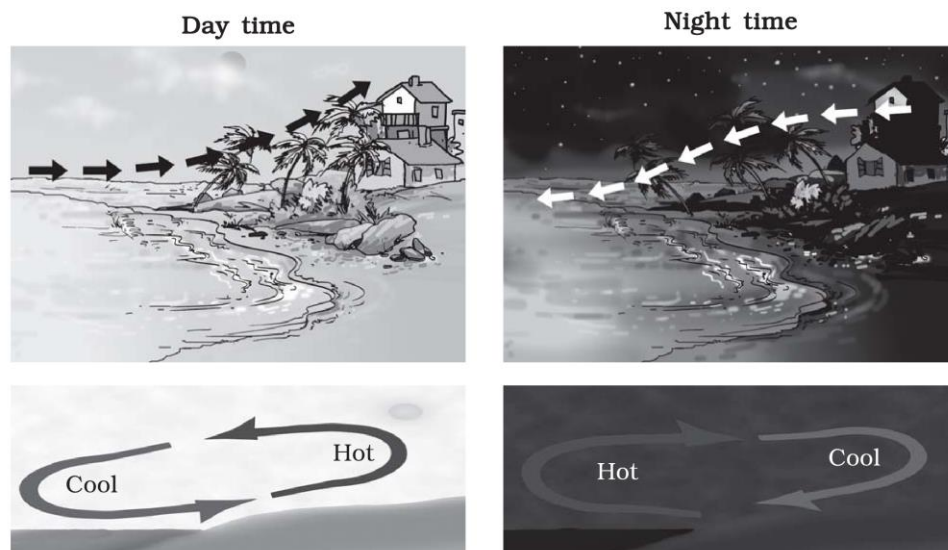


Fig. 4.11 Land breeze and sea breeze

- From the sun the heat comes to us by another process known as radiation.
- The transfer of heat by radiation does not require any medium
- When this heat falls on some object, a part of it is reflected, a part is absorbed, and a part may be transmitted.
- All hot bodies radiate a part of the absorbed heat.

Rest of the topics will be uploaded soon.